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INTRODUCTION TO NONDESTRUCTIVE TESTING

Prepared under Contract NAS 8-20185 by

Convair Division
General Dynamics Corporation
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for George C. Marshall Space Flight Center
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Introduction to Non Destructive Testing CR 61204

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PREFACE

Introduction to Nondestructive Testing is home study material for familiarization and orientation on nondestructive testing. The handbook has been prepared in a self-study format including self-examination questions.

Introduction to Nondestructive Testing should be completed prior to reading other reports in the series. The material presented in these documents will provide much of the knowledge required to enable each person to perform his nondestructive testing job effectively. However, to master this knowledge considerable personal effort is required.

This nondestructive testing material is part of a large program to create an awareness of the high reliability requirements of the expanding space program. Highly complex hardware for operational research and development missions in the hazardous and, as yet, largely unknown environment of space makes it mandatory that quality and reliability be developed to levels heretofore unknown. The failure of a single article or component on a single mission may involve the loss of equipment valued at many millions of dollars, not to mention possible loss of lives, and the loss of valuable time in our space timetable.

A major share of the responsibility for assuring such high levels of reliability lies with NASA, other Government agencies, and contractor nondestructive testing personnel. These are the people who conduct or monitor the tests that ultimately confirm or reject each piece of hardware before it is committed to its mission. There is no room for error--no chance for reexamination. The decision must be right--unquestionably--the first time. This handbook is one step toward that goal.

The recipient of this handbook is encouraged to submit recommendations for updating and comments for corrections of errors in this initial compilation and general technical questions to the George C. Marshall Space Flight Center, Quality and Reliability Assurance Laboratory (R-QUAL-OT), Huntsville, Alabama 35812.

ACKNOWLEDGMENTS

This handbook was prepared by the Convair Division of General Dynamics Corporation under NASA Contract NAS8-20185. Assistance in the form of process data, technical reviews, and technical advice was provided by many companies and individuals. We gratefully acknowledge this assistance and express our gratitude for the high degree of interest exhibited by these firms, their representatives, and other individuals who, in many cases, gave considerable time and effort to the project.

Our thanks is also extended to the many individuals who assisted in the testing of the materials to validate teaching effectiveness. Their patience and comments contributed greatly to the successful completion of the handbook.

INTRODUCTION

This handbook is the first in a series on nondestructive testing training. It will teach you the basic steps in metal processing and how breaks, such as cracks and holes, occur in metal as a result of this processing.

This volume is intended as a point of departure for training in the nondestructive methods. It is required reading before you read the other reports on nondestructive testing methods listed below:

Liquid Penetrant Testing

Magnetic Particle Testing

Eddy Current - Volumes I and II

Ultrasonics - Volumes I, II and III

Radiography - Volumes I through V

INSTRUCTIONS

The pages in this book should not be read consecutively as in a conventional book. You will be guided through the book as you read. For example, after reading page 3-12, you may find an instruction similar to one of the following at the bottom of the page —

- Turn to the next page
- Turn to page 3-15
- Return to page 3-10

On many pages you will be faced with a choice. For instance, you may find a statement or question at the bottom of the page together with two or more possible answers. Each answer will indicate a page number. You should choose the answer you think is correct and turn to the indicated page. That page will contain further instructions.

As you will soon see, it's very simple — just follow instructions.

TURN TO THE NEXT PAGE

Why do customers today place a very high emphasis on quality in nearly every purchase they make? The answer is simple. The complex products being marketed today require much greater reliability in each component to assure trouble-free service for a reasonable period of time.

Product quality is necessary because of the performance expectation of the customer. The housewife expects her refrigerator to give uninterrupted service for years. A husband expects the car to start every morning, and to carry him to and from work without mechanical difficulties. Each of these products contain many components, any one of which could make the refrigerator or car unusable if the component failed. Consider all of the electronic parts contained in a modern tape recorder, a stereo set, or TV set. Each part must be of high quality so that the whole unit will give trouble free service for a reasonable period of time.

From the above, you can conclude that the customer is demanding which of the following? (Choose one and turn to the page indicated.)

A less costly product . . . . Page 1-2
Customer satisfaction . . . . Page 1-3
A reliable product . . . . Page 1-4

Yes, everyone is demanding a less costly product. But no one wants a less costly product if it breaks down all the time.

The user of a product buys it with every expectation that it will give trouble-free service for a reasonable period of usefulness. If you buy a cheap TV set, you may find that the set cannot be relied upon--it may break down all the time. A less costly product does not assure product quality.

This does not mean that all low priced items are unreliable nor does it mean that all high priced items are reliable and of good quality. The relationship between price and quality depends on the manufacturer.

Return to page 1-1 and try one of the other answers.

All right. Let's say the customer is demanding satisfaction. But let us take a deeper look into just what that means.

Customer satisfaction stems from a product that is reasonably priced and has proven that it has a reasonable life expectancy.

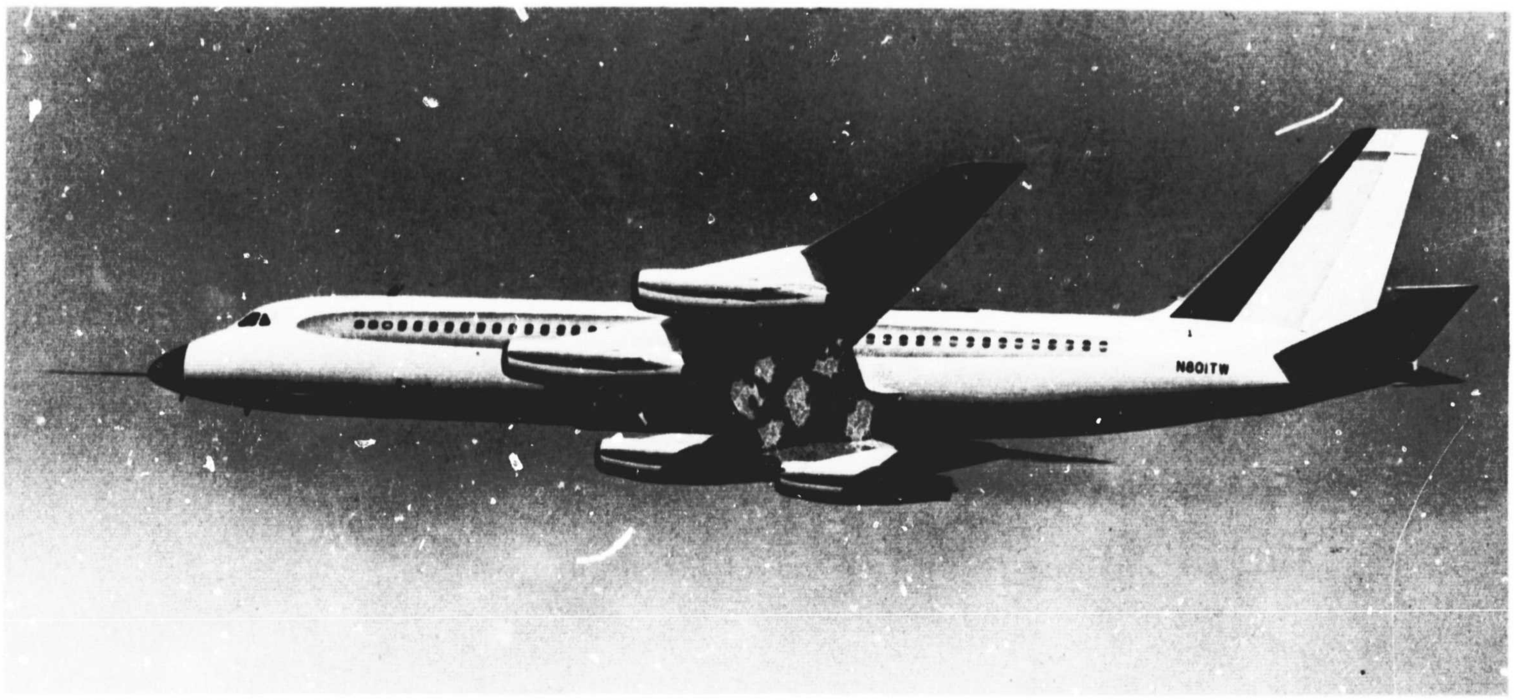
Using an electric razor for example: if its blades are not sharpened to the degree the customer expects, he will be dissatisfied because his shave will be both uncomfortable and unclean. On the other hand, the electric razor will not satisfy the customer, if after a few shaves, the originally sharp blades become dull or the motor no longer operates.

Most customers do not want to buy a product which has to be continually repaired-- even if the repairs are free. So you see, the customer is demanding something more than satisfaction.

Return to page 1-1 and find the correct answer.

That's right. The customer is demanding a reliable product. For example, a family of modest means could not afford to buy a TV set that breaks down all the time.

In the aerospace industry, the problem of reliability is magnified many times. A manufacturer or modern jetliners is dealing with a product costing on the order of five million dollars and the lives of about 130 people every time the jetliner flies. You can see why an airline company purchasing an airplane would demand a reliable product.



Considering the hundreds of thousands of critical parts used in the construction of a jetliner, the task of obtaining the desired level of reliability is monumental. What can happen if a fuel line breaks in a jet engine pod? What can happen if a flight control cable breaks or comes loose in flight? What can happen if the landing gear fails to extend for landing? The lives of all on board are jeopardized and five million dollars may go down the drain.

Considering the above, what do you think the customer is demanding now?

Customer satisfaction . . . . Page 1-5
One hundred percent reliability . . . . Page 1-6
A less costly product . . . . Page 1-7

You feel the customer is demanding satisfaction. Well, not much satisfaction can be obtained after a jetliner crashes and all of its occupants are killed. There is nothing to be gained by demanding satisfaction in this case.

No, the customer is demanding something more than satisfaction. He is buying a jetliner for five million dollars to haul 130 people around. His first demand is that the jetliner function without fail.

Return to page 1-4 and study the problem again.

From page 1-4

Good for you! That's absolutely right. The customer is demanding one-hundred percent reliability. And rightfully so for the customer must protect his investment and his good name.

The highest product quality is needed to assure reliability not only for jetliners but for space launch vehicles and their associated spacecraft. Consider the thoughts of an astronaut in preparing for a space flight.

The astronaut knows that the retro-rockets must fire to bring the spacecraft out of orbit. The control system must function or he will be unable to position the spacecraft for re-entry and it will burn up in the atmosphere during re-entry.

If you were the astronaut preparing for orbital flight, what would be your primary concern?

I would hope everything works . . . . Page 1-8

I would hope for one-hundred percent reliability . . . . Page 1-9

I don't think one-hundred percent reliability is possible . . . . Page 1-10

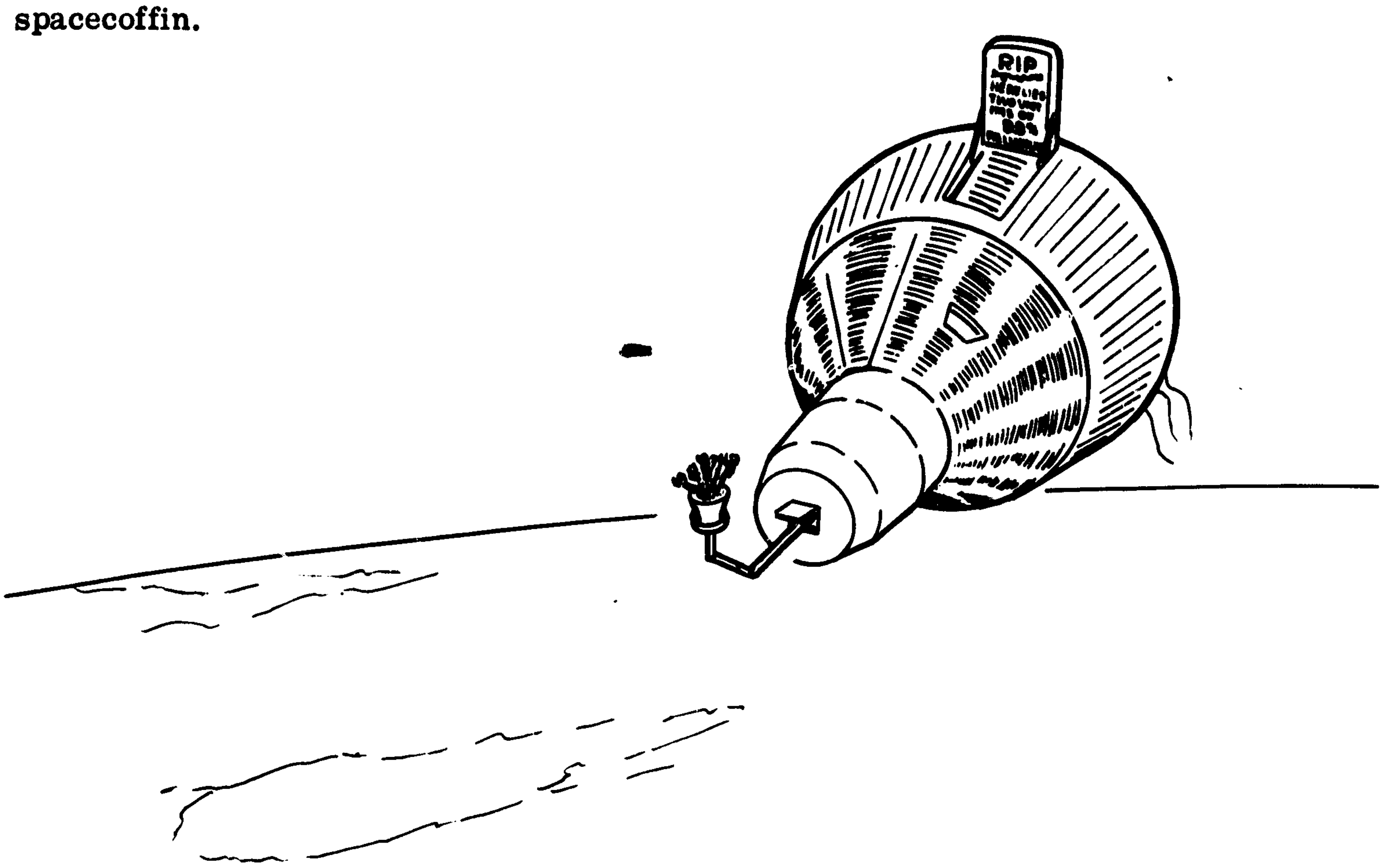
You feel the customer is demanding a less costly product. The customer certainly wants to get as much for his money as possible but not to the extent of sacrificing the reliability of the jetliner.

With five million dollars invested and the lives of about 130 passengers involved every time the jetliner flies, don't you think the airline would want the jetliner to operate properly every time it flew?

Return to page 1-4 and try again.

From page 1-6

You bet your life you would hope everything works. A spacecraft is not an attractive coffin. If the retro-rockets failed to fire, that's exactly what you would have--a spacecoffin.



This is exactly why we need greater quality in these days of rapid technological advancement. Consider the first telephone conversation weighed against inter-continental television and phone calls by communication satellites. Consider the challenge of landing men on the Moon, then Mars as opposed to earth orbital flight. And the only way we can succeed in these endeavors is by producing quality space vehicles that are reliable.

If you were going to the moon in a spacecraft, you would certainly hope for one-hundred percent reliability.

Turn to page 1-9.

From page 1-6

That's right. You would hope for one-hundred percent reliability.

Considering the thousands of individual articles required in the construction of a launch vehicle and its associated spacecraft, one-hundred percent reliability seems like an almost impossible task. But we shouldn't sacrifice even one tiny bit of reliability because of lack of conscientious effort on our part.

Right here is where QUALITY ASSURANCE enters the picture. This is the place where YOU as a member of the QUALITY ASSURANCE TEAM have the opportunity to help make history. How effectively YOU do your job, may well determine whether or not the astronaut makes a successful flight and safe return.

The National Aeronautics and Space Administration (NASA) has embarked on a program which is the greatest technical effort ever undertaken. Intensive scientific investigations are carried out in ever field of modern technology. It employs weather and communications satellites, deep space and lunar probes, and orbiting observatories. The NASA manned space flights are recorded in history. The most ambitious flights remain for the future. As the distance of these flights increases, the reliability and quality requirements will increase four fold. Thousands of problems must be solved, new technologies mastered, space environments charted, and unknown environments studied. These achievements will not depend on a gifted few -- rather, they will represent, now, and in the future, the sum of the contributions of each and every one of us.

Turn to page 1-11

From page 1-6

You don't think one-hundred percent reliability is possible. If you interpret this to mean "perfection," then you are right because true perfection is unattainable. But let's look at that statement from a new point of view.

Let's call our approach a "Zero Defect Program." What this actually means is that once the desired quality level has been established for a specific article, we have ways of eliminating those articles which do not meet these standards. In this way, we can be assured that the article will perform as advertised.

Admittedly, there are many variables involved here and, once in a while, a defective article will slip through. If it is a critical article, the results may be tragic. Any way that you look at it, the least that can be expected of a defective critical article is that failure can cost millions of dollars in the loss of a space launch vehicle or spacecraft.

In direct support of the "Zero Defect Program," we provide back-up systems or other ways of performing critical functions. For example, in spacecraft, two or more methods of controlling attitude are provided since attitude is of grave importance when re-entering the earth's atmosphere. These back-up, or alternate systems, are provided to increase the reliability of spacecraft to as close to 100% as it is possible to get. If you were an astronaut preparing for a space flight, wouldn't you hope for 100% reliability?

With this in mind, turn to page 1-9.

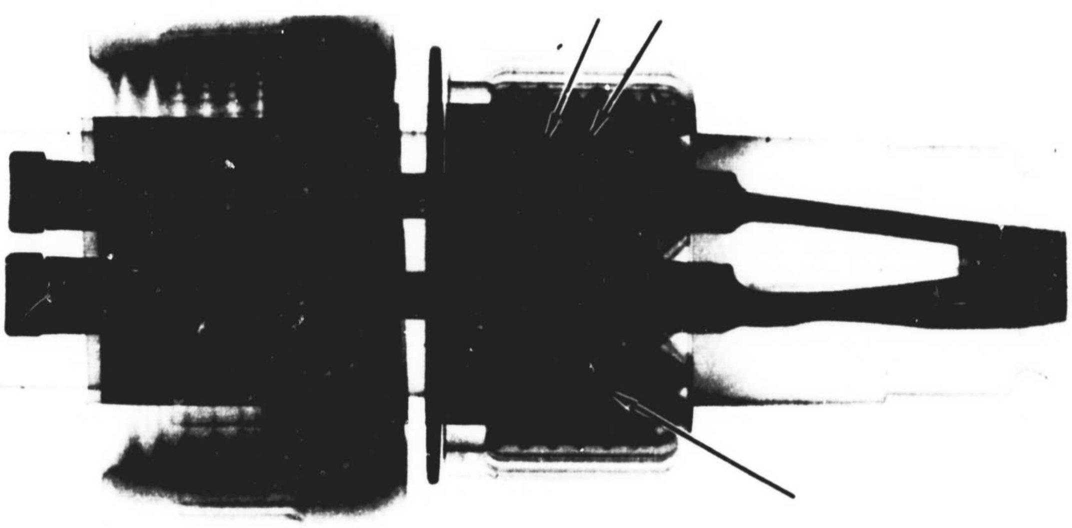
From page 1-9

QUALITY THROUGH NONDESTRUCTIVE TESTING

We have discussed the need for higher quality in terms of the high cost of today's complex equipment and in terms of saving lives. We also pointed out the extreme importance of YOU and every member of the QUALITY ASSURANCE TEAM. Now let us discuss ways of attaining quality through the use of NONDESTRUCTIVE TESTS.

Nondestructive tests are exactly what the name implies--methods of testing articles (parts or materials) for cracks or flaws without damaging the article. A doctor uses many nondestructive tests in a physical examination. He taps the knee to determine the condition of the reflex functions of the nervous system. The doctor takes an X-ray to test the condition of the lungs--he is examining the inside of the body without damaging any part of the body.

X-rays are widely used to examine the inside of aerospace articles. This nondestructive test is called Radiographic Testing. Here is an X-ray of an electrical connector on a space launch vehicle.



This article connects the circuit from the autopilot to the vernier adjusting boosters which control the flight path of the launch vehicle. The arrows point to foreign objects found in the connector. These objects are pieces of solder which could short the connection causing the launch vehicle to crash or fail to achieve the correct space flight path. Through the use of radiographic testing of the electrical connector a catastrophy was averted.

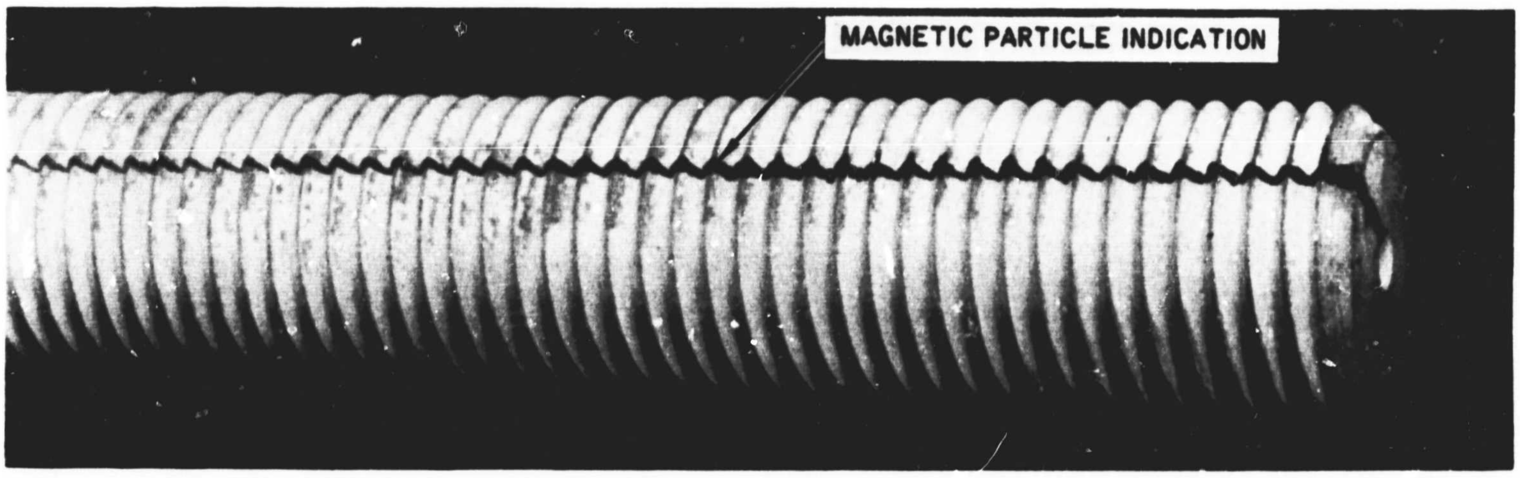
Turn to the next page.

There are many methods of nondestructive testing to locate holes, cracks, or breaks in the continuity of the materials or articles. The nondestructive tests we will be concerned with are:

LIQUID PENETRANT TESTING (PT)
MAGNETIC PARTICLE TESTING (MT)
RADIOGRAPHIC TESTING (RT)
EDDY CURRENT TESTING (ET)
ULTRASONIC TESTING (UT)

Notice the symbols in parenthesis at the end of each test method. These symbols are used on engineering drawings to designate the test method or methods to be used in determining the quality of a specific article.

Each nondestructive test is designed to provide visual evidence of flaws in articles which are not normally visible to the unaided eye. The visual evidence left by each method is called an INDICATION. The indication may be an accumulation of magnetic particles as in magnetic particle testing. It is the accumulation of magnetic particles that we see and not the crack.



Other indications may be in the form of a cathode ray tube reading for ultrasonic testing, or in the form of X-ray film reading in the case of radiographic testing. NONDESTRUCTIVE TESTS, then, are methods used to determine the performance capabilities of materials or articles without damaging them. If the test method is properly selected for a specific article, and the test itself is properly performed, you can be sure that the article has no flaws and will meet the quality requirements.

Turn to the next page for a table which briefly describes the nondestructive testing methods.

From page 1-12

NONDESTRUCTIVE TESTING METHODS

	LIQUID PENETRANT TESTING	MAGNETIC PARTICLE TESTING	RADIOGRAPHIC TESTING	EDDY CURRENT TESTING	ULTRASONIC TESTING
DEFINITION	USES A PENETRATING LIQUID TO SEEP INTO A SURFACE DISCONTINUITY THUS PROVIDING A VISIBLE INDICATION.	USES ELECTRICAL CURRENT TO CREATE A MAGNETIC FIELD IN A SPECIMEN WHILE MAGNETIC PARTICLES INDICATE WHERE THE FIELD IS BROKEN BY A DISCONTINUITY.	USES ELECTROMAGNETIC RAYS (X-RAYS AND GAMMA RAYS) TO PENETRATE MATERIAL, RECORDING ON FILM DISCONTINUITIES IN THE MATERIAL.	USES AN ELECTRICAL CURRENT IN A COIL TO INDUCE EDDY CURRENTS INTO A SPECIMEN. INDICATORS REVEAL DISCONTINUITIES THAT ALTER THE PATH OF THE INDUCED CURRENTS.	USES ULTRASOUND TO PENETRATE MATERIAL, INDICATING DISCONTINUITIES ON AN OSCILLOSCOPE SCREEN.
USES	USED ON METAL, GLASS, CERAMICS TO LOCATE SURFACE DISCONTINUITIES. SIMPLE TO USE AND DOES NOT REQUIRE ELABORATE EQUIPMENT.	USED ON METAL WHICH CAN BE MAGNETIZED (FERROMAGNETIC) TO DETECT SURFACE OR SUBSURFACE DISCONTINUITIES. SIMPLE TO USE AND EQUIPMENT IS PORTABLE FOR FIELD TESTING.	USED ON ANY METAL STOCK OR ARTICLES, AS WELL AS A VARIETY OF OTHER MATERIALS TO DETECT (AND RECORD ON FILM) SURFACE OR SUBSURFACE DISCONTINUITIES. FILM PROVIDES A PERMANENT RECORD OF THE DISCONTINUITIES.	USED ON METALS TO DETECT SURFACE AND SUBSURFACE DISCONTINUITIES, HARDNESS, AND THICKNESS. PLATING COATING (NON-METALLIC), AND SHEET THICKNESS MEASUREMENTS.	USED ON METAL, CERAMICS, PLASTICS, ETC., TO DETECT SURFACE AND SUBSURFACE DISCONTINUITIES. WHEN AUTOMATED, INDICATIONS ARE RECORDED ON PAPER, PROVIDING A PERMANENT RECORD. ALSO MEASURES MATERIAL THICKNESS.
LIMITATIONS	DOES NOT DETECT DISCONTINUITIES BENEATH THE SURFACE OF A SPECIMEN.	CANNOT BE USED ON METAL WHICH CANNOT BE MAGNETIZED. REQUIRES ELECTRICAL POWER.	HIGH INITIAL COST. REQUIRES ELECTRICAL POWER SOURCE. POTENTIAL SAFETY HAZARD TO PERSONNEL.	INSPECTION DEPTH LIMITED TO LESS THAN ONE INCH. DOES NOT GIVE PHYSICAL SHAPE OF DISCONTINUITIES.	MODERATELY HIGH INITIAL COST. REQUIRES ELECTRICAL POWER SOURCE. INTERPRETATION OF TEST RESULTS REQUIRES HIGH-TRAINED PERSONNEL.

Turn to the next page.

DESTRUCTIVE AND NONDESTRUCTIVE TESTS

Nondestructive tests are an essential supplement to destructive tests. DESTRUCTIVE TESTS destroy the article being tested. These tests usually bend, twist, or break the article being tested and destroy its usefulness for service. Since these tests destroy the article, this type of testing is usually costly and is limited to testing a small percentage of a group of specific articles. Destructive tests assume those articles not tested have equal quality. Such an assumption is not adequate for aerospace articles where each and every one must meet rigid standards of quality and reliability.

This is where nondestructive tests supplement destructive tests. Nondestructive tests determine the qualities of a part without altering or changing its physical qualities or usefulness. Thus, each and every article is inspected without damaging its physical structure. Therefore, nondestructive tests supplement percentage destructive tests and give further assurance that all articles meet quality standards.

Today's aerospace designs are being pushed to the limits of available materials, engineering knowledge, and processes to produce required systems components. More than ever before, reliability and freedom from maintenance are required of the end item. Nondestructive tests are an absolute necessity to give all possible assurance that an article meets the required quality level and will perform as expected. Space, weight, or cost limitations often prevent overdesign with the large built-in safety factors formerly permissible. Thus, nondestructive testing serves as a very important tool in QUALITY ASSURANCE.

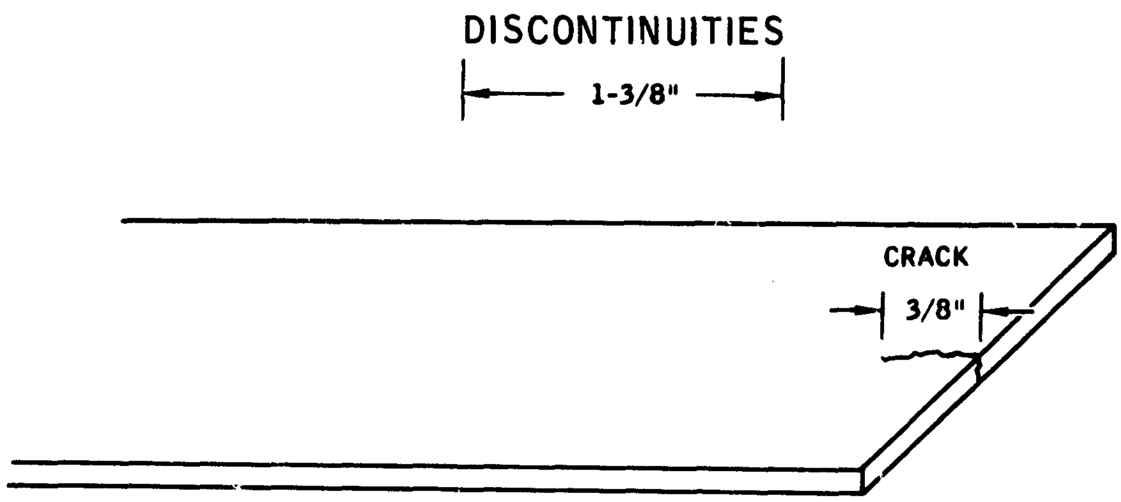
Turn to the next page.

DISCONTINUITIES

Up to this point, we have used words such as breaks, cracks, holes, and flaws to show the type of things we will be looking for with nondestructive tests. All of these can be summed up in one word: DISCONTINUITIES.

The word dis-con-ti-nu-i-ty simply means: A BREAK OR INTERRUPTION IN THE NORMAL PHYSICAL STRUCTURE OF AN ARTICLE.

Many discontinuities will not be half so long as the name which has been given them.



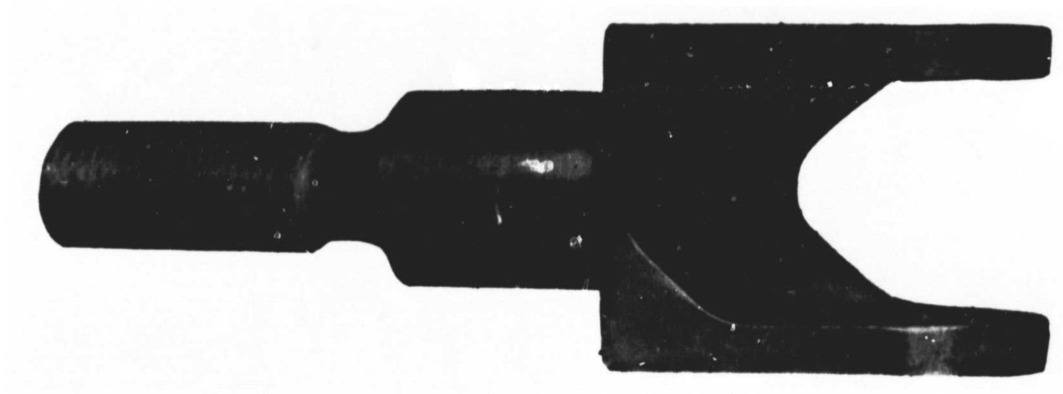
Of course, we are making a joke in the illustration. But in nondestructive testing, discontinuities are no joke--THEY ARE AN INTERRUPTION IN THE NORMAL PHYSICAL STRUCTURE OF AN ARTICLE.

Turn to the next page.

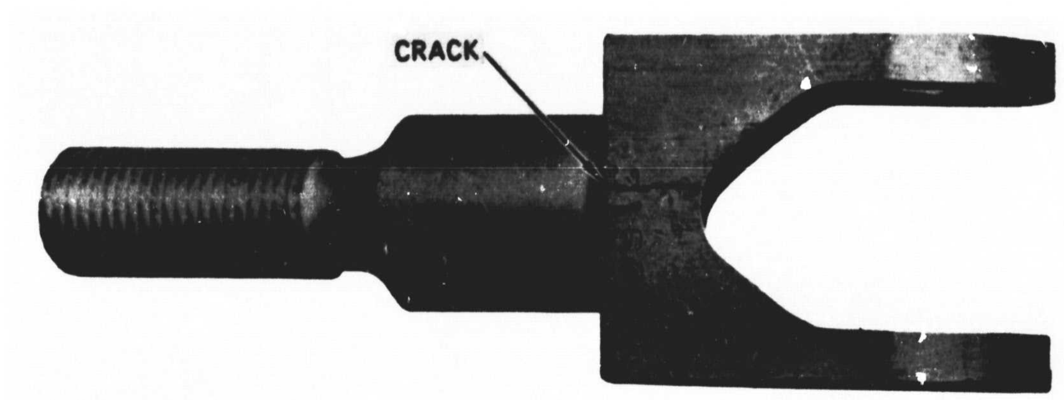
From page 1-15

A discontinuity in metal may be a hole, crack, flaw, or anything else that breaks the continuity of the metal. Discontinuities may be found on the surface of the metal or within the metal itself.

The portion of the article you see below has continuity of structure--it has no cracks or other flaws.



However, turn the article over and you can see the other side is cracked. The crack is an interruption in the normal physical structure of the article.



The crack in the above article would be called a:

Discontinuation . . . . Page 1-17
Discontinuity . . . . Page 1-18

No, that crack would not be called a discontinuation. This word is similar in meaning to the correct word but is not the one which is used.

The crack in that article is to be called a discontinuity which is defined as:

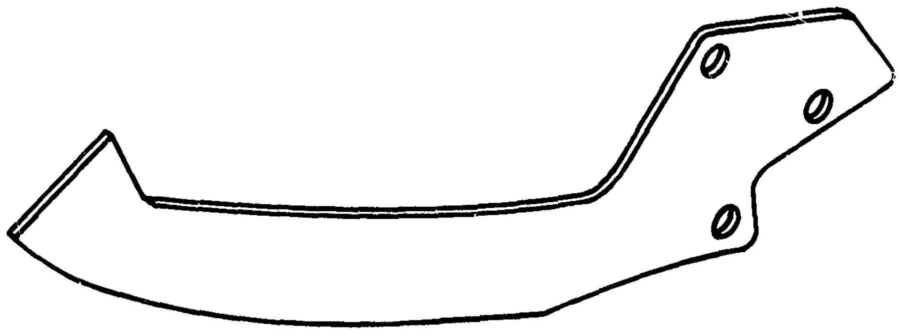
A BREAK OR INTERRUPTION IN THE NORMAL PHYSICAL STRUCTURE OF AN ARTICLE.

Turn to page 1-18.

From page 1-16

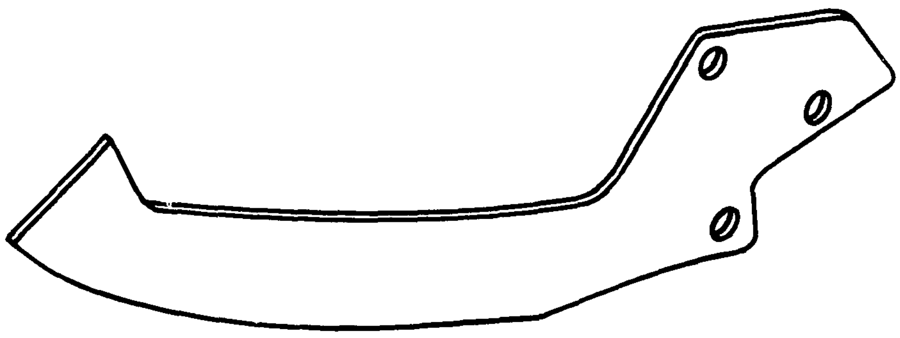
Right. That crack is called a discontinuity--a break or interruption in the normal physical structure of the article.

Shown below are two launch vehicle engine supports. Without visible discontinuities, they would look like this:



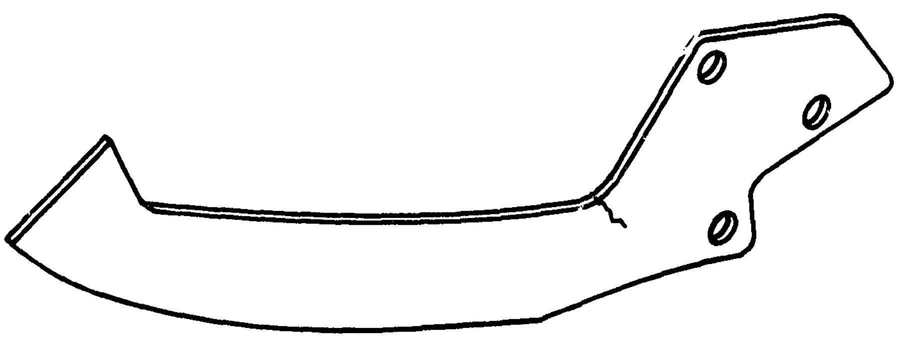
Which of the two below, if either, has a visible discontinuity?

1.



. . . . Page 1-19

2.

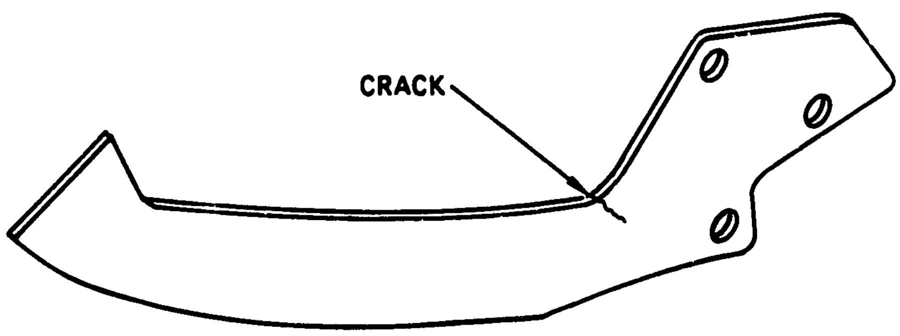


. . . . Page 1-20

From page 1-18

No, the first engine support did not have a discontinuity.

Remember, a DISCONTINUITY IS A BREAK OR INTERRUPTION IN THE NORMAL PHYSICAL STRUCTURE OF AN ARTICLE. Any kind of a crack or flaw is called a discontinuity.

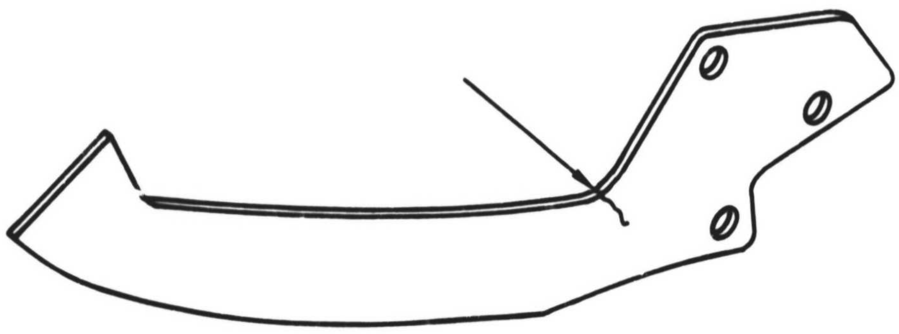


That crack in the engine support was the discontinuity--it is a break in the normal physical structure of the engine support.

Turn to page 1-20.

From page 1-18

Fine. The second launch vehicle engine support has a small but visible discontinuity--a crack.



Here is an article that was to be used in a space vehicle launcher. To the unaided eye, the cracks were not visible. Fortunately, the article was subjected to a nondestructive test and the cracks were located before the article was installed in the launcher.

The cracks are discontinuities because they are an INTERRUPTION IN THE NORMAL PHYSICAL STRUCTURE OF THE ARTICLE. A hole, crack, or flaw of any type is called a discontinuity.

This, then, is the role of NONDESTRUCTIVE TESTS in the Quality Assurance Program--to locate the many types of discontinuities found in the many types of materials used in aerospace end items such as the X-15, space launch vehicles and their associated spacecraft, ground support systems, etc.

Turn to the next page.

From page 1-20

THE ORIGINS OF DISCONTINUITIES

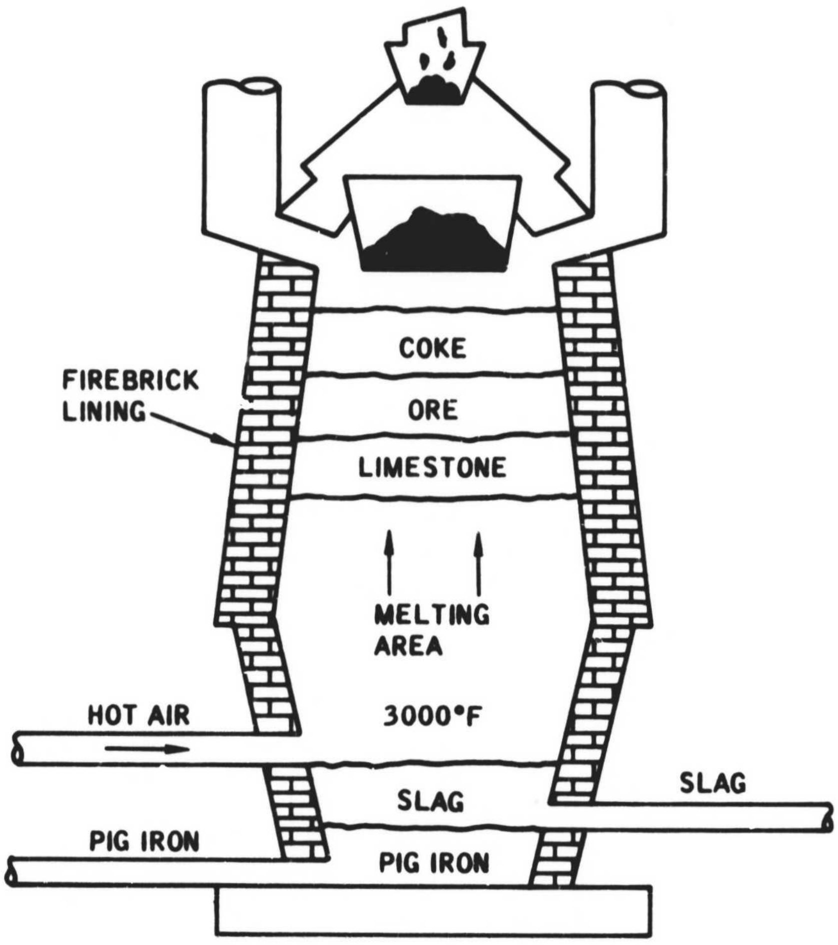
In the previous section, we pointed out the various nondestructive test methods and their role in the QUALITY ASSURANCE PROGRAM. We found that each method provides visual indications of flaws, holes, cracks, etc., which are not normally visible to the unaided eye. We found that these breaks or interruptions in the normal physical structure of an article are called DISCONTINUITIES.

Before any nondestructive test method can be put to intelligent use, it is necessary to understand why discontinuities are found in materials. To do this, we are now going to discuss the refining processes that transform various mined ores into usable materials. We are also going to discuss the various metal forming processes to understand why specific discontinuities take the shape they do. The smelting and forming processes are the guiding factors in determining the types of discontinuities and where they may be expected to appear in an article as a result of a specific forming process.

Since the causes for discontinuities in all metals are similar, we will discuss only the processing of steel. Some discontinuities found in ferrous metals have their beginning at the steel mill when the iron ore is melted in blast furnaces. Ferrous is defined as: of or pertaining to iron. Thus, steel is a combination of materials most of which are derived from iron.

Turn to the next page.

The steel-making process begins with iron ore, coke, and limestone which are fed into the top of a blast furnace. As the coke burns, an intense heat is created which removes the oxygen from the iron ore and allows the molten metal to trickle to the bottom of the furnace.



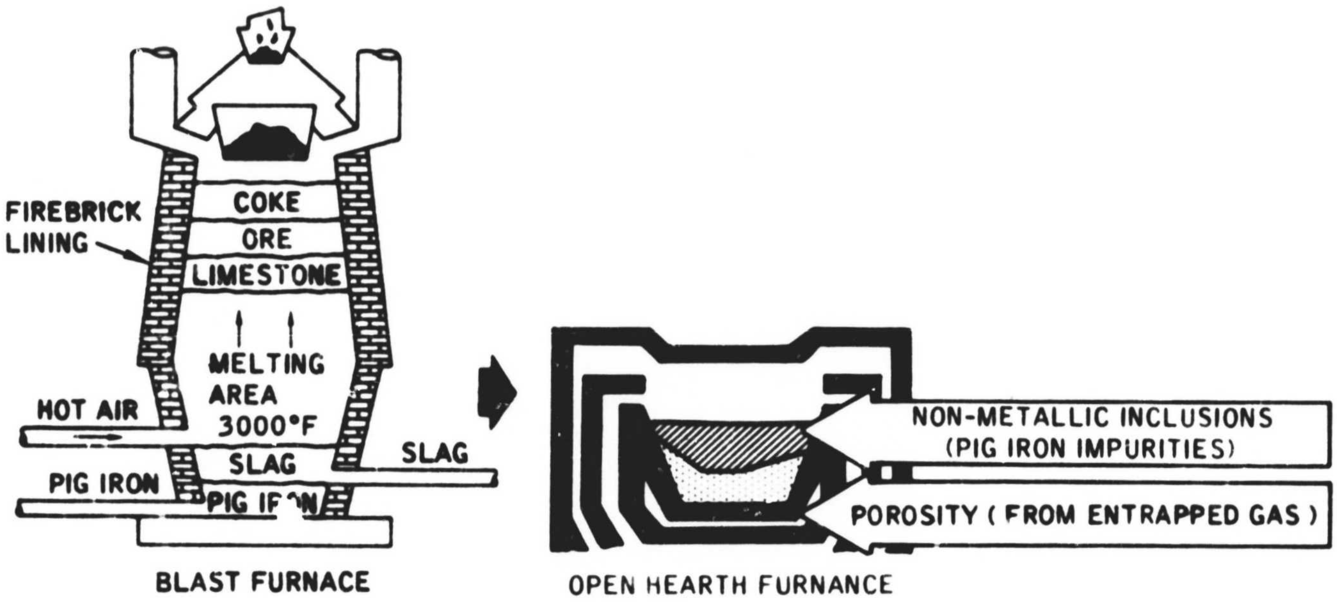
The limestone gathers the impurities in the iron ore to it and the impurities become liquid. Like the iron, these impurities trickle to the bottom of the furnace but, because they are lighter than the molten iron, the impurities remain on top and are called slag. Since the slag is made up of impurities, it is not wanted and is drawn out of the furnace. Most of the slag is removed in this way but some remains and combines with the molten iron. It is this slag which later forms some of the discontinuities found in metals.

Turn to the next page.

As the molten iron is drawn from the blast furnace, it is poured into molds to form what is called "pig iron." This name came from an early process in which molten iron was poured into large molds called "sows." These sows allowed the molten metal to trickle into smaller molds resembling suckling pigs. Thus, the name pig iron.

Like its namesake, pig iron is not too clean. As the pig iron hardens, the slag impurities also harden into slate-like pockets within the metal. The impurities are not metallic and were accidentally included in the iron. These pockets of slag in the iron are called NON-METALLIC INCLUSIONS.

Pig iron is the first product in the steel-making process. It is too brittle for most purposes, so it is processed in an open hearth furnace, along with other materials, to make better quality metal.



Pig iron is refined and other metals or alloys are added to produce steel having desired physical properties. Do you think the finished steel will still contain non-metallic inclusions? Take a guess.

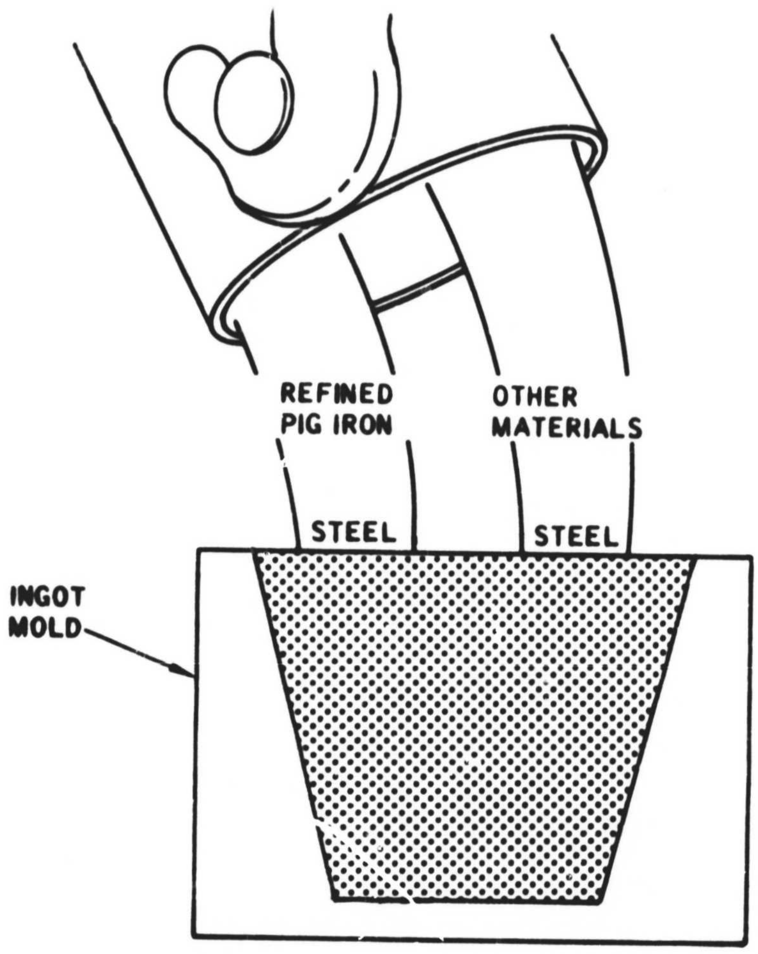
Yes . . . . Page 1-24
No . . . . Page 1-25

From page 1-23

Absolutely. Finished steel will contain NON-METALLIC INCLUSIONS. That was a good guess.

When the molten steel with its pig iron and other alloys is ready, it will be poured into molds to form INGOTS. Ingots may be small or they may weigh as much as 250 tons.

Pouring of the ingots is what we have been working toward, for metal parts are formed from the ingots.

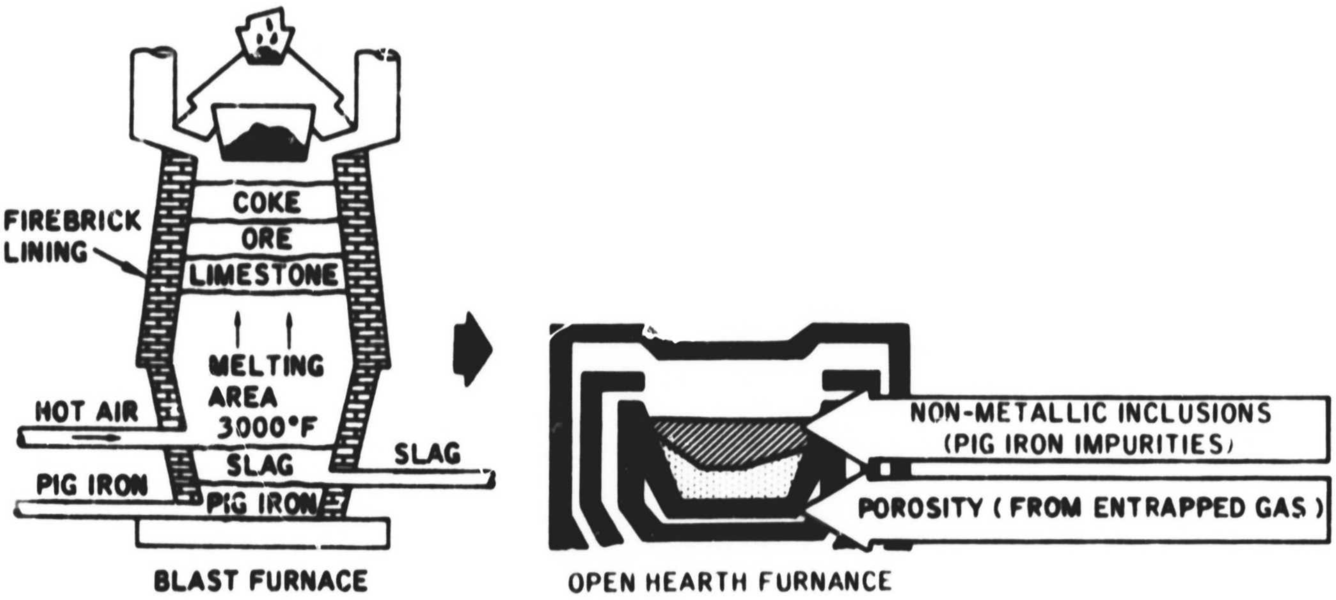


Here you see the molten steel as it is being poured into the ingot mold. Although the open hearth furnace refining process has eliminated some impurities others have formed.

Would you expect to find non-metallic inclusions in the above-pictured ingot?

Yes . . . . Page 1-26
No . . . . Page 1-27

You guessed--"No." Actually, the finished steel will still contain non-metallic inclusions and here's why.

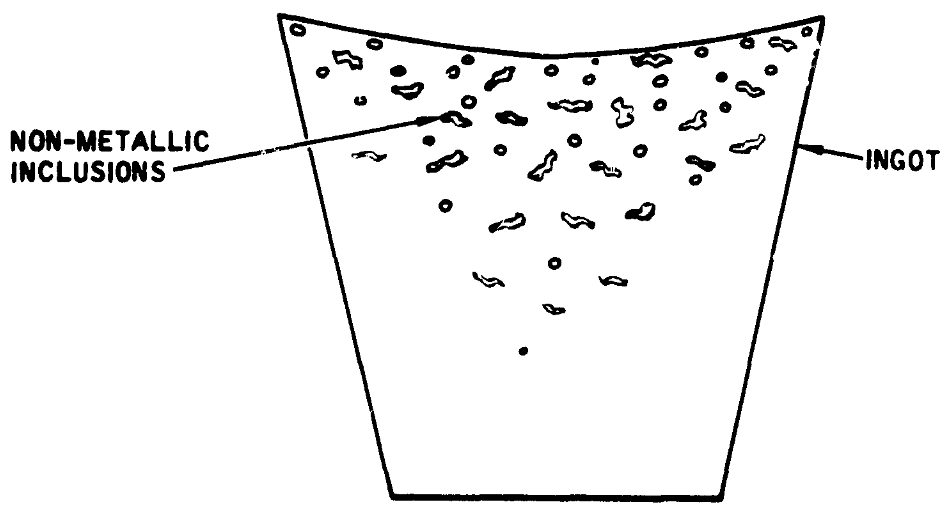


Most of the slag is eliminated at the blast furnace but some of the impurities still remain with the molten iron. The molten iron is then placed in the open hearth furnace where it is further refined. However, some of the non-metallic material still remains. In addition, due to the process itself, gas bubbles, or porous areas, may form. So you see, the ingot has non-metallic inclusions and, in addition, may have a certain amount of entrapped gas.

Turn to page 1-24.

That's right. You certainly would find non-metallic inclusions in the ingot. Impurities formed as a result of the refining process, cause pockets of foreign material called non-metallic inclusions.

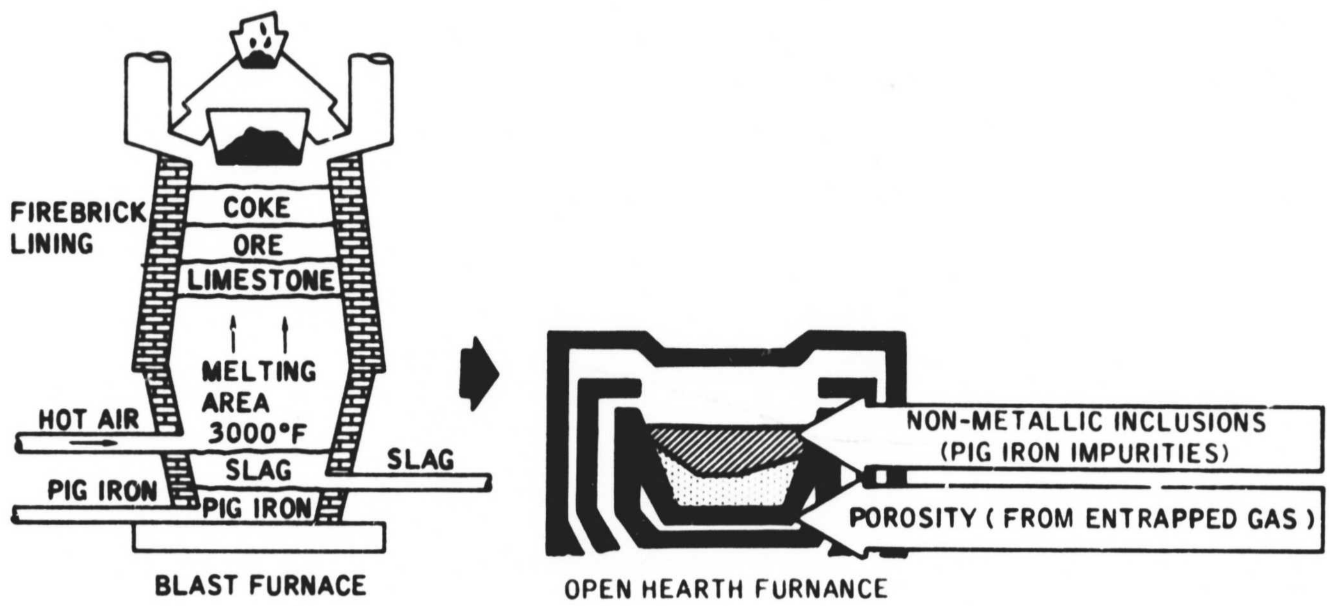
The non-metallic inclusions within the molten metal are lighter than the metal and rise toward the surface. Most of the non-metallics manage to rise to the upper part of the ingot, but some are trapped. They did not have time to reach the surface before the metal hardened above them.



From the above, you can see that NON-METALLIC INCLUSIONS in the hardened ingot, would look like which of the following?

Irregular discontinuities . . . . Page 1-28
Round discontinuities . . . . Page 1-29
Both of the above . . . . Page 1-30

You selected--No. You would not expect to find non-metallic inclusions in the ingot. Actually, the open hearth furnace will eliminate some of the impurities or non-metallic inclusions but not all of them.



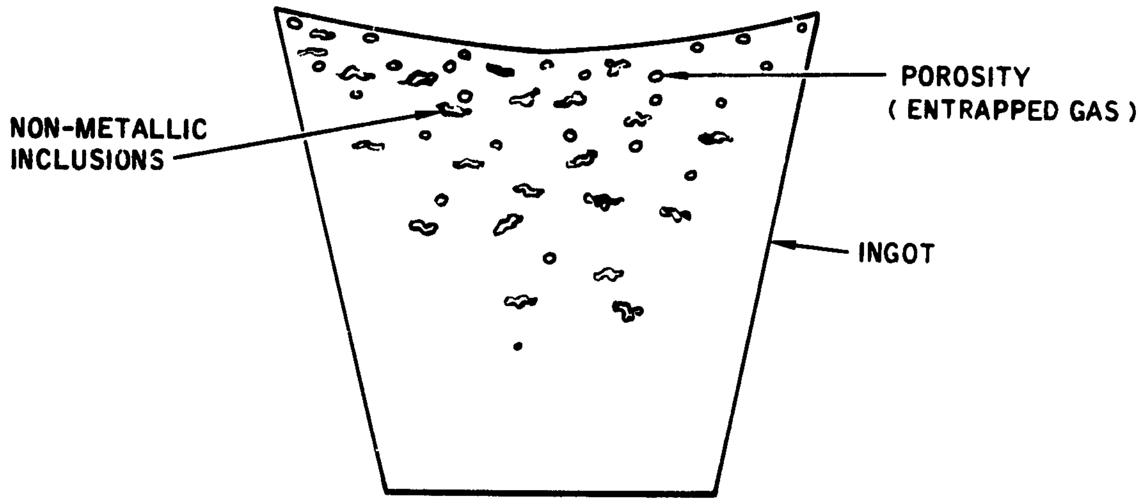
Remember--although the refining process eliminates SOME of the impurities, it does not eliminate all of them. The ingot will contain some non-metallic inclusions. In fact, other discontinuities are added as you can see from the above illustrations.

Turn to page 1-26.

From page 1-26

Right. Non-metallic inclusions in ingots appear as irregular-shaped discontinuities.

The irregular-shaped non-metallic inclusions are not the only discontinuities found in ingots. Ingots also contain entrapped gas with a bubble like appearance. These bubbles occur from gasses formed in the metal when it was melted in the furnace. Some of the gas remains in the metal when it is poured into the ingot mold.



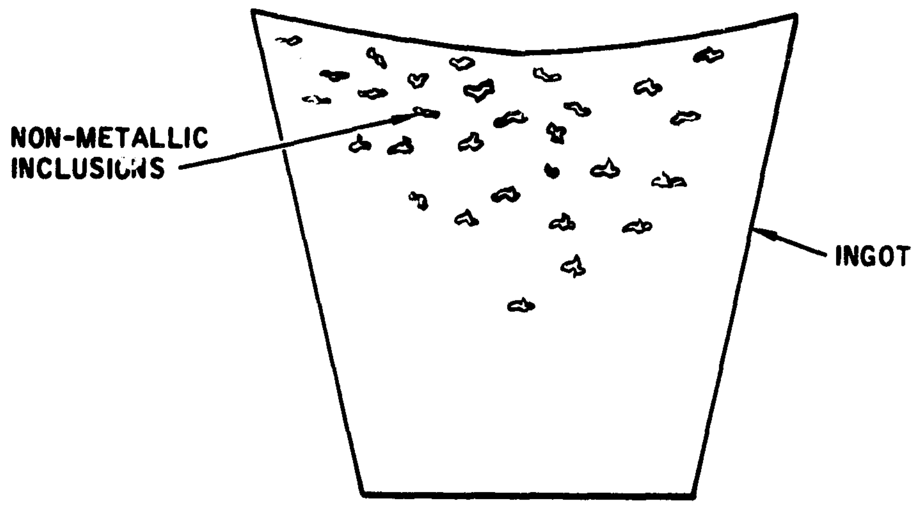
The gas bubbles are much like the bubbles in a bottle of pop. Like non-metallic inclusions, the gas bubbles rise toward the surface as the ingot hardens. Most of the bubbles reach the surface. But again, as in the case of the non-metallic inclusions, some of the bubbles are trapped by the hardening metal. They are called POROSITY.

From the illustration above, you can tell that POROSITY differs from non-metallic inclusions because:

Porosity is round in shape . . . . Page 1-31
Porosity consists of round inclusions . . . . Page 1-32

From page 1-26

You are guessing. Let's look at the ingot again. Those non-metallic inclusions don't look round do they?



The dark spots in the ingot represent non-metallic inclusions.

Return to page 1-26 and try again.

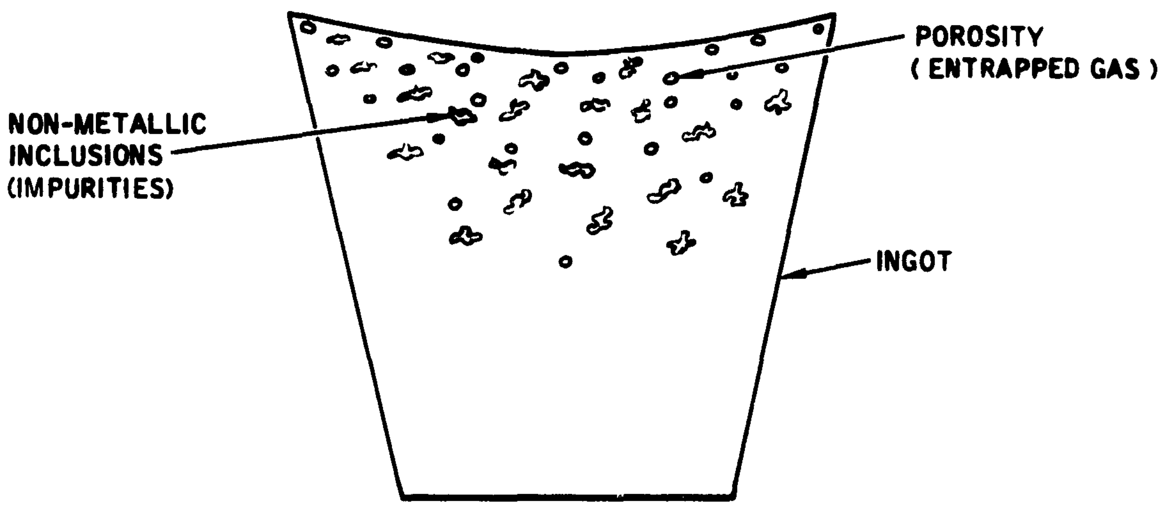
From page 1-26

You think that non-metallic inclusions in a hardened ingot would appear both irregular and round. Well, it is possible that you could find a blob of impurities that would approximate roundness but it would most likely be very ragged.

In the usual sense, non-metallic inclusions are very ragged. The dark spots in the illustration represent non-metallic inclusions.

Return to page 1-26 and try again.

Yes sir. Porosity is round.



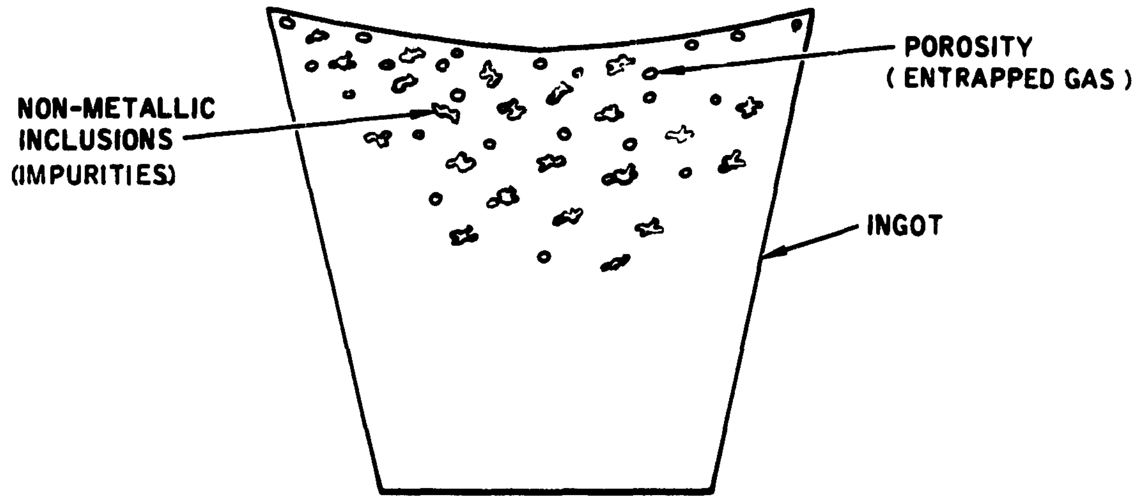
Since both non-metallic inclusions and porosity are breaks or interruptions in the normal physical structure of the ingot, they can be called:

Breaks . . . . Page 1-33

Flaws . . . . Page 1-34

Discontinuities . . . . Page 1-35

You think porosity consists of round inclusions. No, you see porosity is formed by gas bubbles. Non-metallic inclusions are formed by slag impurities.



Here, you can see the difference. Non-metallic inclusions are pockets filled with foreign material. Porosity is caused by trapped gasses and the round holes have no solid material in them. So porosity is round or nearly round.

Turn to page 1-31.

From page 1-31

Yes, both porosity and non-metallic inclusions are breaks in the structure of the ingot, but didn't we agree that all of the different names would be combined into one? We also gave the term we were to use a definition. Here it is.

A BREAK OR INTERRUPTION IN THE NORMAL PHYSICAL STRUCTURE OF AN ARTICLE.

Return to page 1-31 and pick the correct name for this definition.

From page 1-31

Yes, both porosity and non-metallic inclusions are flaws in the structure of the ingot. But didn't we agree that all of the various names would be combined into one for our purposes? We also gave the term we were to use a definition. Here is the definition.

A BREAK OR INTERRUPTION IN THE NORMAL PHYSICAL STRUCTURE OF AN ARTICLE.

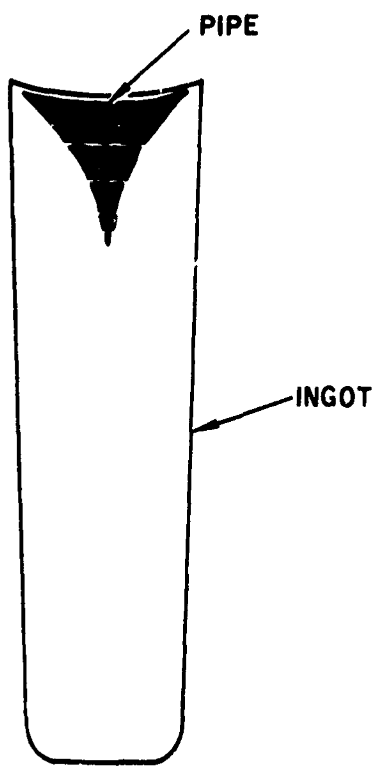
Return to page 1-31 and select the word which we have defined.

From page 1-31

Very good. Both non-metallic inclusions and porosity are breaks or INTERRUPTIONS IN THE NORMAL PHYSICAL STRUCTURE OF THE INGOT and are, therefore, DISCONTINUITIES.

Ingots are made in many sizes and shapes. The shape depends upon what the ingot is to be used for. If the ingot is to be rolled into plate stock, it would be poured in a relatively flat rectangular mold. If the ingot is to be used for making bar stock, it would be poured into a longer and thinner round or square mold. The different types of ingot molds, in conjunction with the different steel making methods, result in other types of discontinuities. Let us consider one of these now.

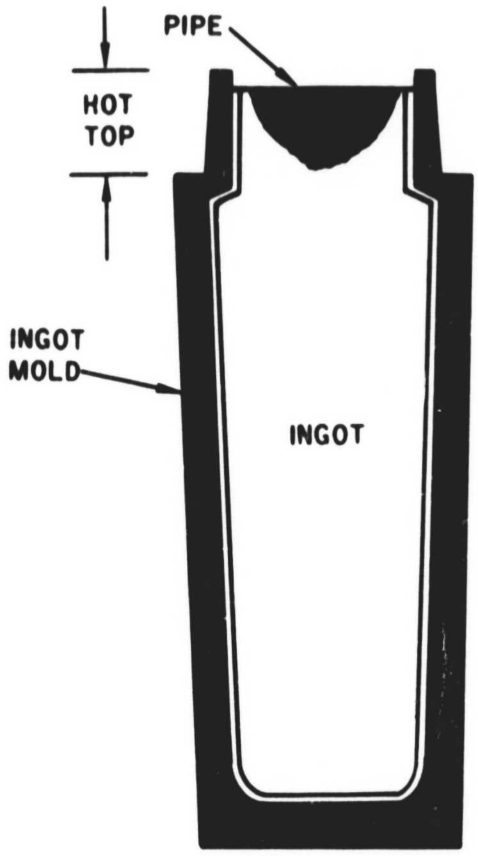
Here is an ingot designed to be rolled into bar stock. At the top you can see a severe shrinkage depression. It is caused by molten metal shrinking when it cools and solidifies. The depression is called "PIPE."



In the molten condition, the metal expands. In other words, molten metal occupies more space than does the hardened metal. When the molten metal starts to cool and harden, it shrinks. Since the center of the ingot is last to cool and harden, most of the shrinkage is absorbed in the center. This results in the cavity called "PIPE."

Turn to the next page.

Since "pipe" in the end of the ingot makes that portion of the ingot unusable, most ingot molds in use today have an added portion which acts as a reservoir and absorbs most of the ingot shrinkage. The reservoir is called the "hot top."

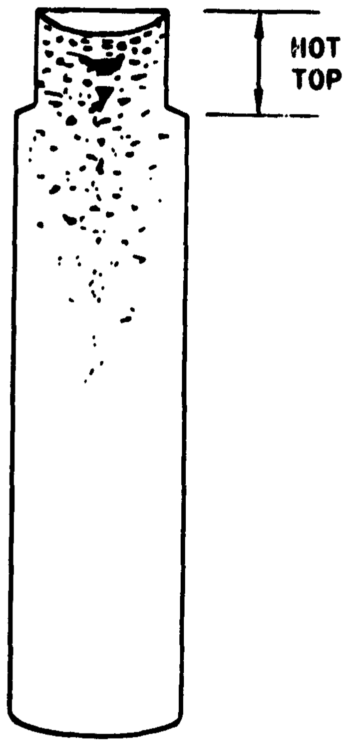


The "hot top" is designed to absorb as much of the pipe as possible. It is also used to absorb some of the non-metallic inclusions and porosity. As we have mentioned before, the type and quantity of a specific discontinuity is dependent upon the method of metal processing and on the type of ingot mold.

Do you think the "hot top" would eliminate all of the non-metallic inclusions, gas bubble porosity, and pipe?

Yes . . . . Page 1-37
No. . . . . Page 1-38

You think the hot top <u>would</u> eliminate all of the non-metallic inclusions, gas bubble porosity, and pipe. Actually, those discontinuities are more widely distributed than was indicated in that last illustration. Take a look at this one.



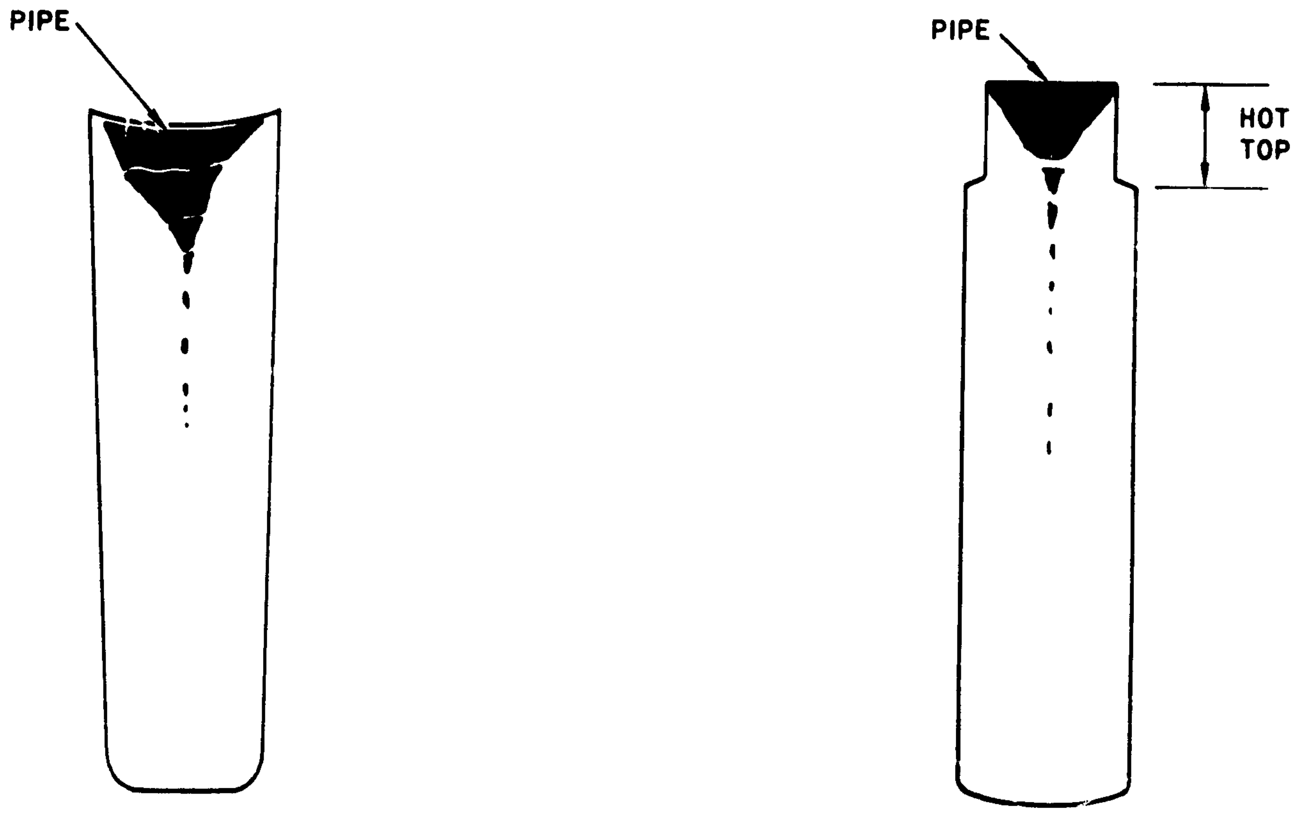
Here you can see the distribution of discontinuities in this particular ingot and they are not all located in the "hot top." Of course all ingots will not have such a wide distribution of discontinuities as this one. The point to be made here is that the "hot top" does not absorb all of the discontinuities -- it will not eliminate all of them from the ingot.

Turn to page 1-38.

From page 1-36

Correct. The hot top will not eliminate all of the different discontinuities. Here are some examples.

Here are some ingots cast with and without hot tops. The ingot on the left was poured in a mold without a hot top and you can see the pipe (shrinkage cavity) extends deep into the center of the ingot. The ingot on the right was poured with a hot top and you see the pipe still extends very deeply into the ingot.

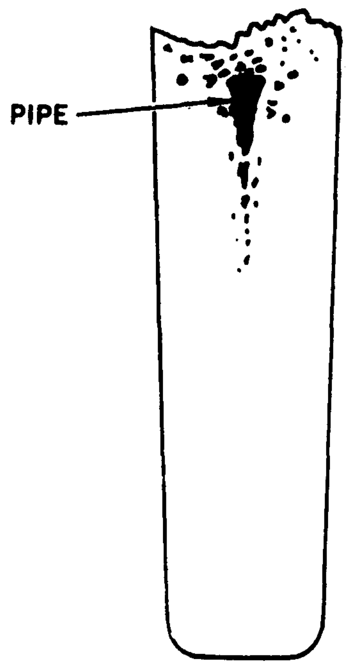


The only difference here is the shape of the shrinkage cavity or "pipe" in the two ingots. The intermittent cavities extending deep into the ingot are individual extensions of the main cavity. They are also called pipe as they were caused by shrinkage as the molten metal solidified. We can conclude from the above that pipe is caused by:

Shrinkage as the metal solidifies . . . . Page 1-39
Expansion as the metal solidifies . . . . Page 1-40

Absolutely. Pipe is caused by shrinkage as the metal solidifies.

Pipe is not always obvious in an ingot. It can be covered up. Here is an example.



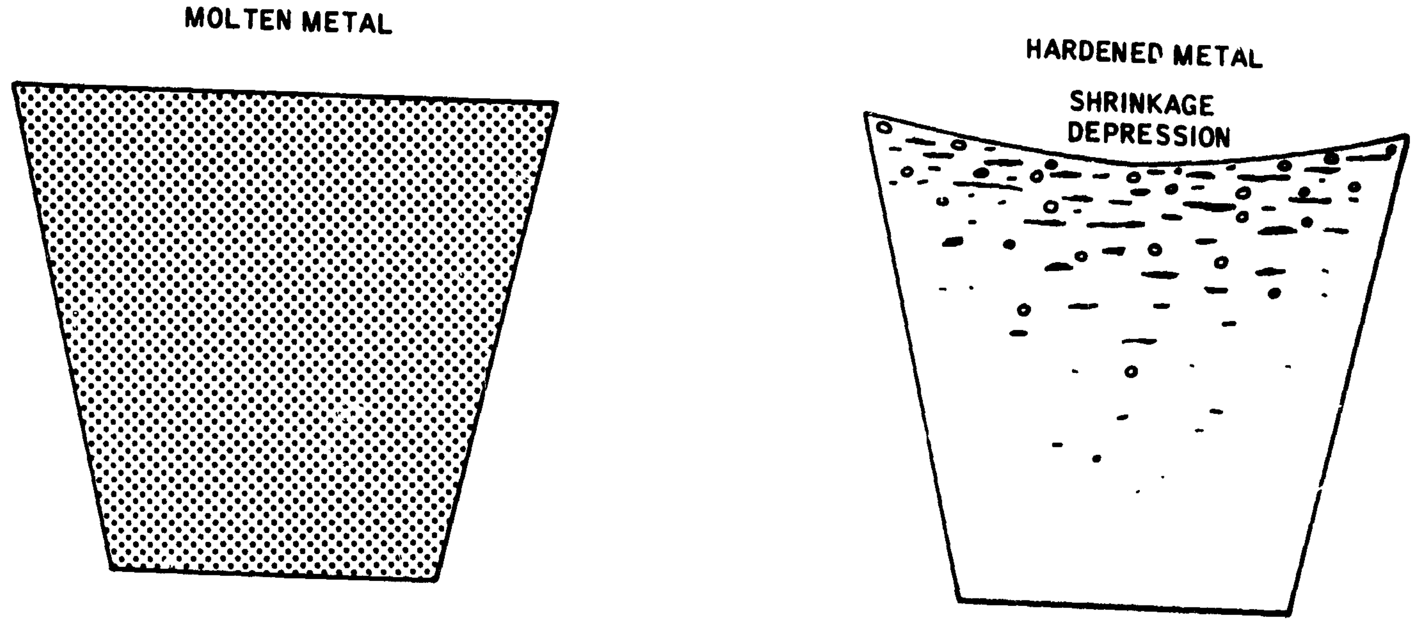
In this case, excessive gas pressure forced molten metal up through the hardening top causing a bleeding action. The bleeding covers the pipe as shown in the illustration. Since excessive gas pressure was present in this ingot, what other type of discontinuity would you expect to find in the ingot?

Non-metallic inclusions . . . . Page 1-41

Porosity . . . . Page 1-42

From page 1-38

You think that "pipe" is caused by expansion as the metal solidifies. No, the metal does not expand when it starts to harden. It shrinks. These two illustrations demonstrate our point.

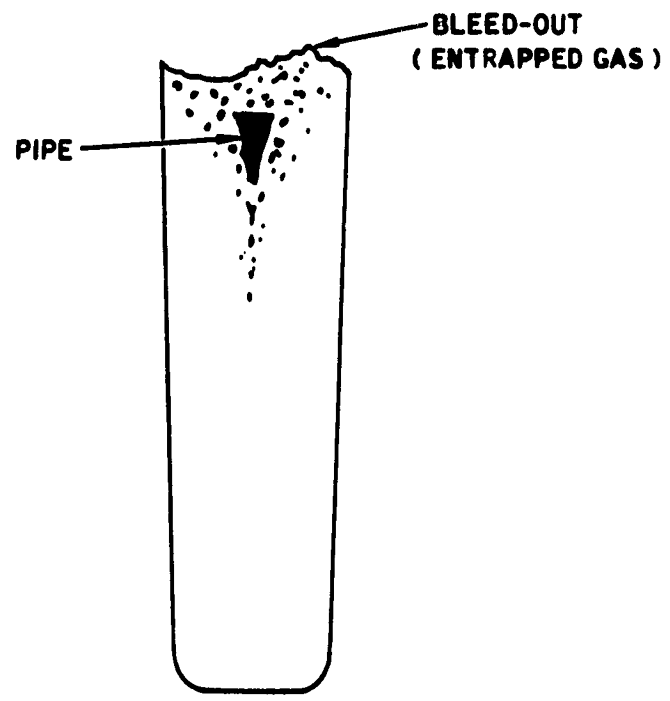


When the molten metal is poured into the mold, it fills the mold. When the metal hardens, it shrinks causing a shrinkage depression as shown by the illustration on the right. In the ingot we were discussing, the shrinkage was more pronounced. This resulted in the large cavity and the intermittent cavities called pipe. So you see, "pipe" is caused by shrinkage rather than expansion of the metal as it solidifies.

Turn to page 1-39.

From page 1-39

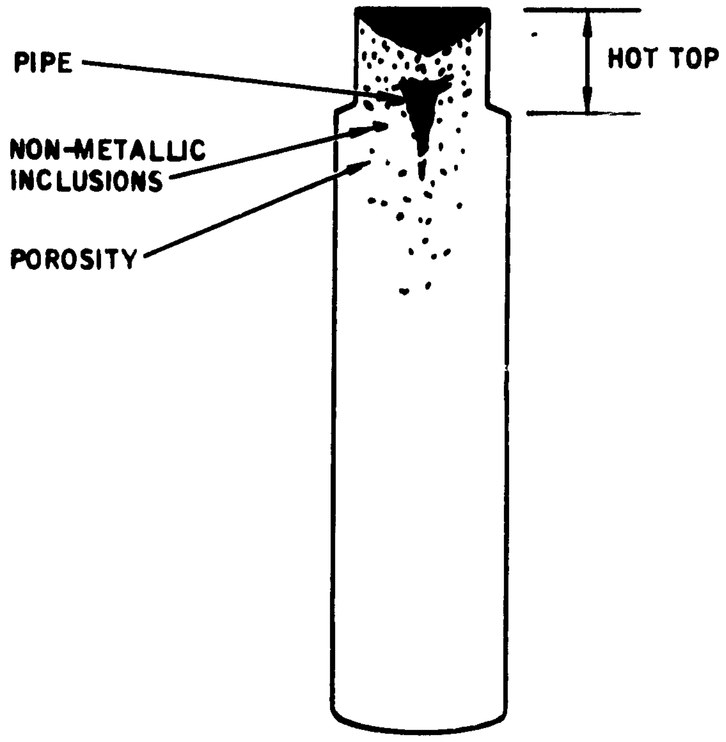
Yes, you would probably find non-metallic inclusions in that ingot. But the point we were trying to emphasize was that there was excessive entrapped gas. In fact, the gas pressure was great enough to force molten metal through the hardening top of the ingot.



Where there is gas, there are gas bubbles which cause porosity.

Turn to page 1-42.

Yes, of course. You would expect to find porosity in the ingot. Entrapped gas cause porosity. Non-metallic inclusions may also be present.



In summary, there are three main types of discontinuities in the ingot:

a. Porosity, which is round or nearly round, and is caused by entrapped gas in the molten metal.

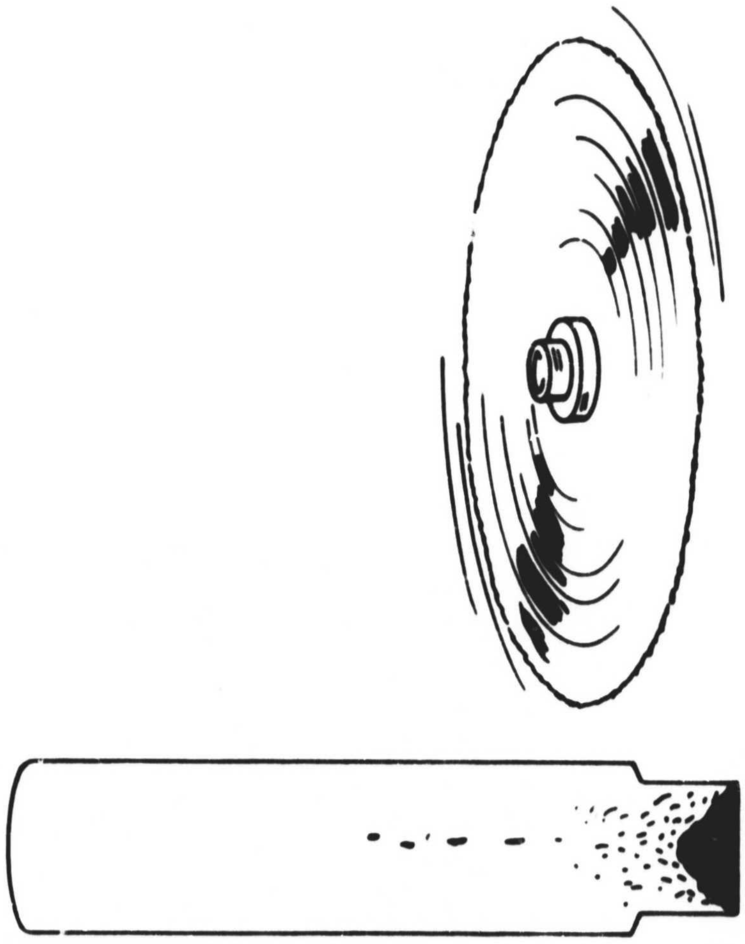
b. Non-metallic inclusions, which are of irregular shape and consist of sla -like impurities accidentally included in the molten metal.

c. Pipe, caused by shrinkage as the molten metal solidifies. It may extend deeply into the center of the ingot.

Turn to the next page.

From page 1-42

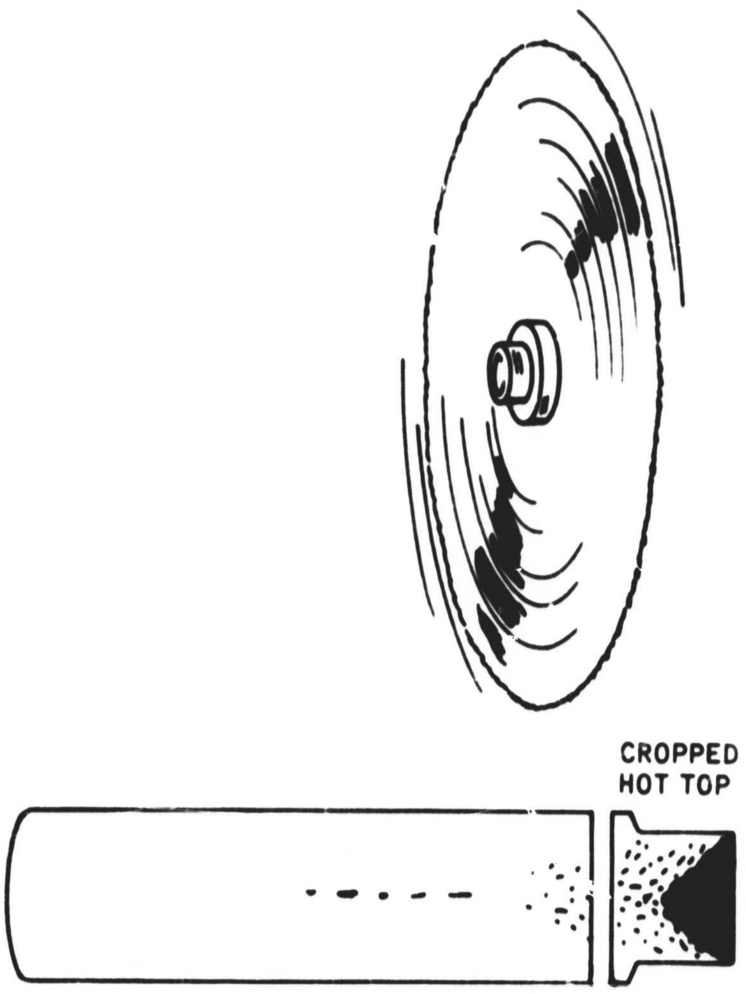
When the ingot solidifies with many of the discontinuities contained in the upper portion, the "hot top" is cut off. To use a steel-man's term, the top of the ingot is "cropped."



Would cropping the top of the ingot remove many discontinuities?

Yes . . . . Page 1-44
No . . . . Page 1-45

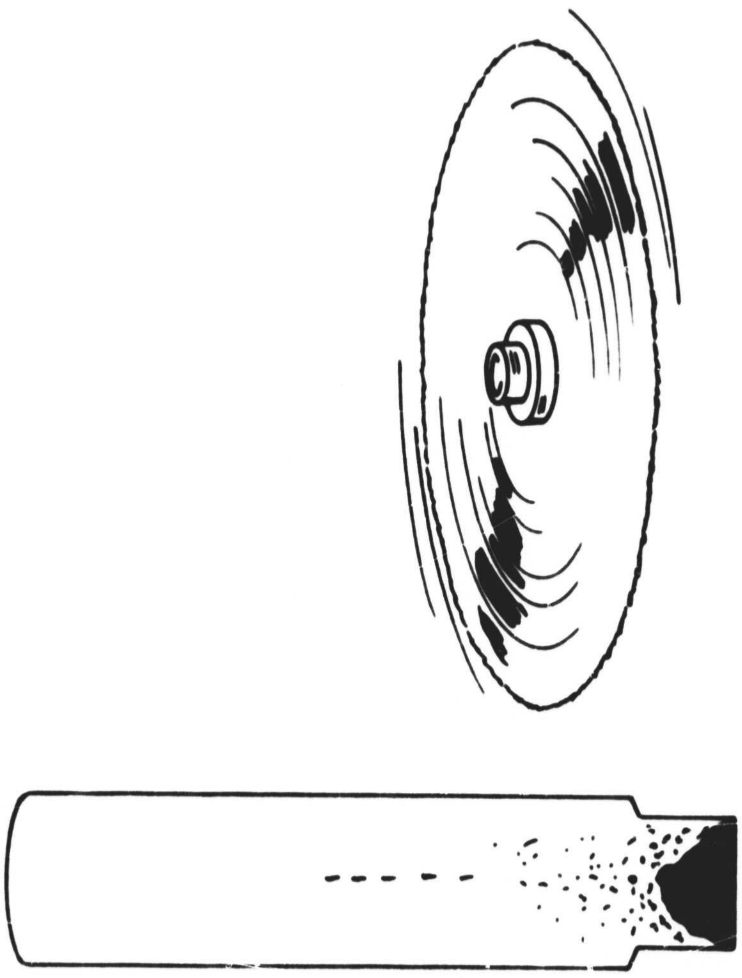
Very good. The cropping or removal of the "hot top" would remove most of the non-metallic inclusions and porosity. It would also eliminate most of the shrinkage depression or "pipe."



Cropping will eliminate all of the "pipe" in the ingot except in those cases where intermittent shrinkage cavities extend deep in the ingot. But are all discontinuities eliminated by cropping?

Yes . . . . Page 1-46
No . . . . Page 1-47

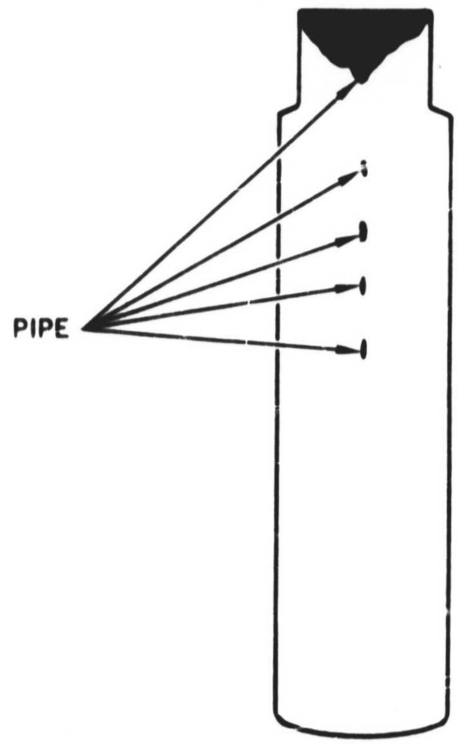
You selected--"No." You must have mis-read the question. Remember, CROPPING means to cut off or remove the "hot top." The hot top is put there to accumulate as many of the discontinuities as possible.



Cutting the top off the ingot will not remove all of the discontinuities. But it will eliminate many of them. Here again remember that the number and type of discontinuities in a specific ingot will depend upon the type of mold used and the smelting process. But, usually, cropping the ingot will remove many of the discontinuities.

Turn to page 1-44.

You think all discontinuities will be eliminated by cropping. That is not right. Unfortunately in most cases, not all of the porosity, non-metallic inclusions, and pipe will be eliminated. Consider the deep-lying shrinkage cavities in this ingot.

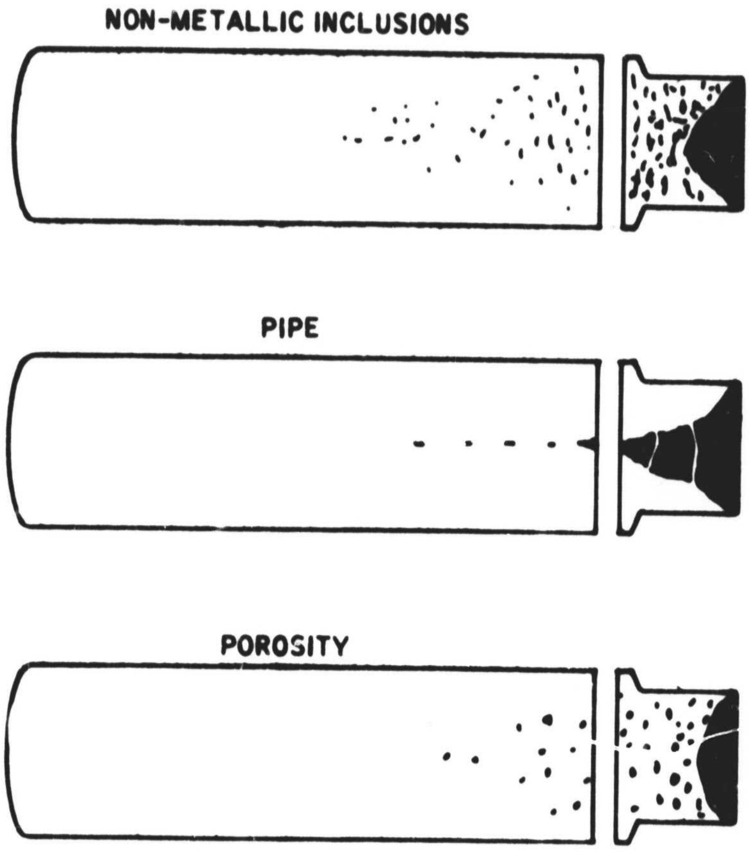


This is a relatively clean ingot with only those four shrinkage cavities or "pipe" that would be left after the top of the ingot is cut off. So you see, not all of the discontinuities will be eliminated by cropping the ingot.

Turn to page 1-47.

From page 1–44

Right. Not all of the discontinuities are eliminated by cropping the ingot. Most of them are eliminated by removing the "hot top." But a few discontinuities remain in the main portion of the ingot.



All of these discontinuities may remain in a single ingot depending upon the type of ingot mold and the method used in refining the metal.

After the top of the ingot is cropped, it gets a new name -- BLOOM — which in turn can be processed into smaller size SLABS or BILLETS. The slab or billet is normally the starting point for actual forming of articles or materials. Before we discuss the forming processes, let's briefly review the material we have covered.

Turn to the next page.

From page 1-47

1. The next few pages are different from the ones which you have been reading. There are ______ arrows on this entire page. (Write in the correct number of arrows.) Do not read the frames below. FOLLOW THE ARROW and turn to top of the next page. There you will find the correct word for the blank line above.

4. article

5. Any crack, break, or flaw in the continuity of the physical structure of an article is called a dis______________ .

8. irregular

9. Due to the refining process itself, all of the material forming gas is not removed from the molten metal. This causes entrapped gas bubbles to form which are called p______________.

12. pipe

13. Because the center of the ingot is last to solidify, most of the shrinkage is absorbed in this area. Intermittent cavities deep in the ingot are called ______________ .

This is the answer to the blank in Frame number 1.

1. four **Frame 2 is next**

2. These sections will provide a review of the material you have covered to this point. There will be one or more blanks in each f________.

Turn to the next page.
Follow the arrow.

5. discontinuity

6. Many discontinuities have their origin in the refining process and are in the molten metal poured into the ________ mold.

9. porosity

10. Gas bubble porosity in the ingot is like bubbles in a bottle of pop. When the ingot hardens, the porosity takes the shape of the gas bubbles which is ________ or nearly ________.

13. pipe

14. Most ingot molds have reservoirs called a "hot top" to absorb as much of the pipe, porosity and non-metallic ________ as possible.

2. frame

3. By following the arrows or instructions you will be directed to the section which follows in sequence. Each section presents information and requires the filling in of ___________ .

6. ingot

7. Slag impurities are not entirely eliminated in the refining process and are found in the ingot as foreign material called non-__________________ inclusions.

10. round, round

11. Another discontinuity is formed when the molten metal shrinks as it hardens. This causes the top of the ingot to have a ____________________ depression.

14. inclusions

15. Pipe, porosity, and non-metallic inclusions are all interruptions in the norm ' physical structure of the ingot and are, therefore, ______________________ .

3. blanks (or spaces or words)

4. Now for the review. Nondestructive tests are methods of detecting interruptions in the normal physical structure of an ar____________.

Return to page 1-48, frame 5.

7. metallic

8. Non-metallic inclusions are ragged when they harden and take an irre____________ shape.

Return to page 1-48, frame 9.

11. shrinkage

12. Due to the shape of some ingot molds, the shrinkage depression can be severe, extending deep into the center of the ingot. This type of depression is called p________.

Return to page 1-48, frame 13.

15. discontinuities

16. Most of these discontinuities are removed from the ingot when the "hot top" is cut off or cropped.

You should not have turned to this page. Return to page 1-48, frame 5.

You should not have turned to this page. Return to page 1-48, frame 9.

You should not have turned to this page. Return to page 1-48, frame 13.

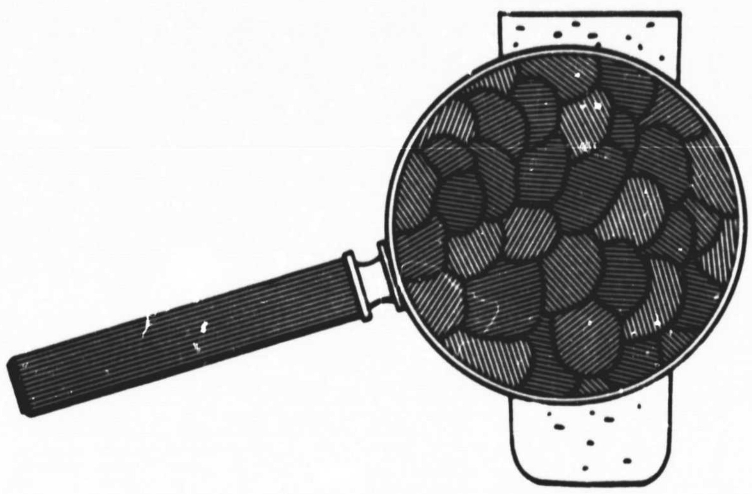
17. Turn to page 2-1.

We have discussed steel-making from the blast furnace to pig iron, through the refining of pig iron and its addition to other metals for casting into an ingot, and cropping of the ingot. We found that the cropped ingot still contains discontinuities such as porosity, non-metallic inclusions, and pipe. Now, for convenience, we are going to discuss the working or forming of a portion of the cropped ingot — a slab or billet.

Working of the billet centers around a vital fact concerning the physical structure of the cast ingot.

> The cast ingot is made up of millions of crystals which, form a CRYSTAL GRAIN STRUCTURE.

Therefore, the billet has a crystal grain structure. If magnifying glass were strong enough, the magnified grains would look something like this.

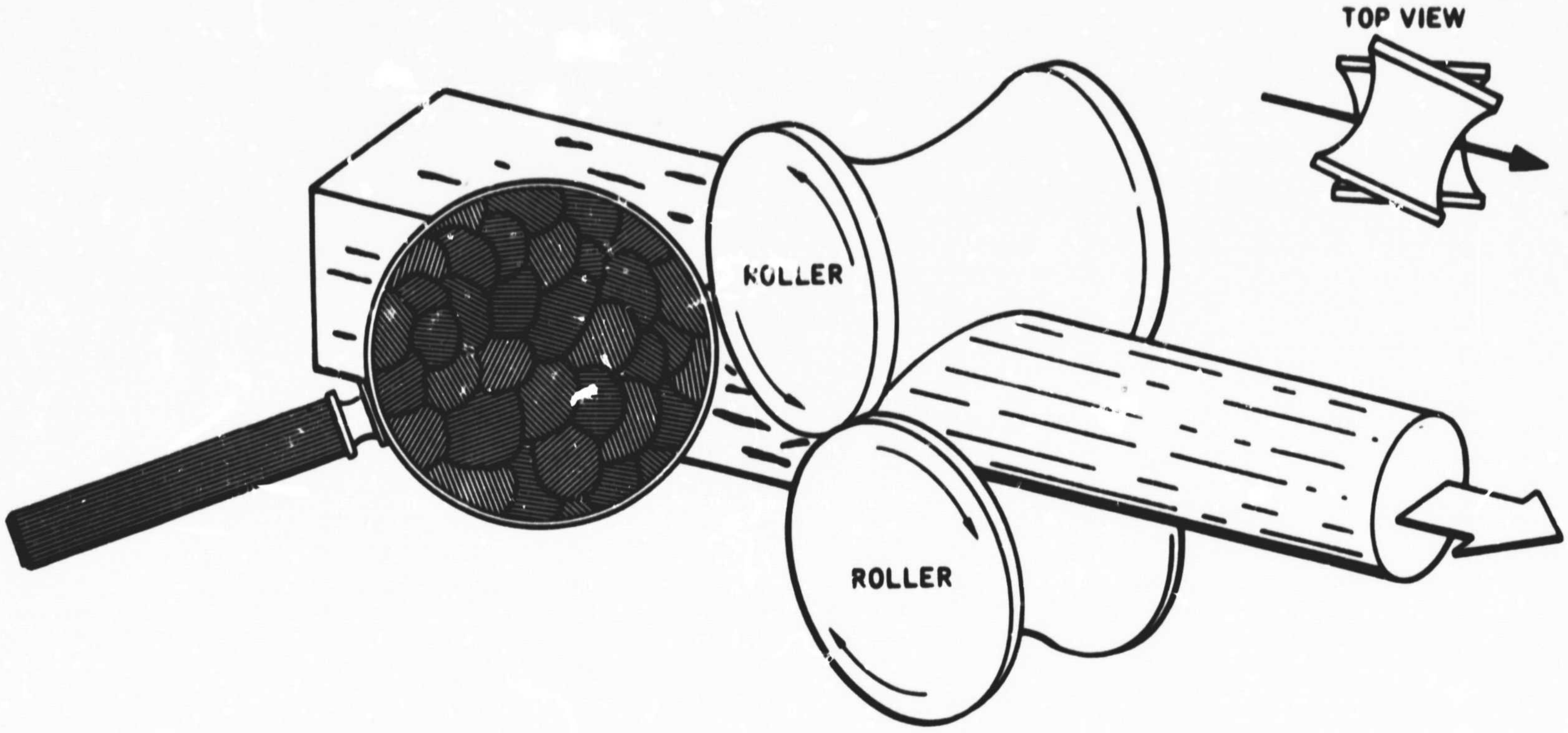


"Working" the metal, such as rolling the billet between heavy rollers to a desired shape, breaks these crystals down. A finer grain is formed and they are STRETCHED OUT IN THE DIRECTION OF ROLL.

Turn to the next page.

Rolling of the billet is usually done after the billet has been heat-soaked in a furnace so that it is evenly heated throughout. Heating allows the crystals to break more easily into smaller grain-shaped crystals in the metal.

After heat-soaking to attain a uniform temperature, the billet is forced between large, heavy rollers. This rolling reduces the thickness of the billet and increases its length.

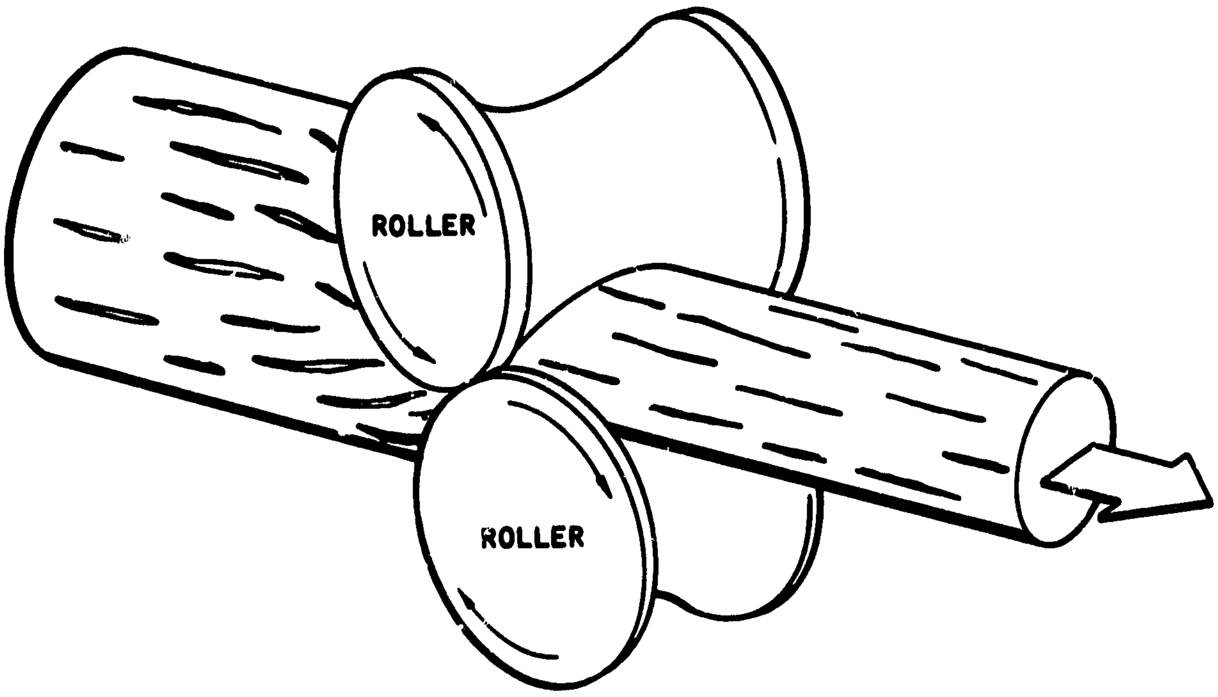


Here you can see the thickness of the billet has been reduced and the length increased. The pressing or squeezing action of the rollers has broken up the crystals which re-form into smaller crystals and a more even grain. The crystals are being stretched out IN THE DIRECTION OF ROLL.

If the billet is rolled another time to increase the length, what do you think will happen to the crystal structure?

The crystals will break into smaller crystals--the grain will be finer . . . . Page 2-3
The crystals will break up and spread out in all directions . . . . Page 2-4

Right you are. The crystals will form finer grain. IT IS IMPORTANT TO REMEMBER THAT GRAIN IN THE METAL IS FORMED IN THE DIRECTION IN WHICH THE METAL IS ROLLED.



Steel is rolled to reduce it in size and to shape it as nearly as possible to the shape of the finished product. It is also rolled to refine the grain structure which makes the metal much stronger.

Which way does the grain form in the bar being rolled above?

Through the length of the bar . . . . Page 2-5
Through the width of the bar . . . . Page 2-6

From page 2-2

Your answer, "... crystals will break up and spread out in all directions," isn't the one we wanted. Let's see why.

The billet is heated to allow the crystals to more easily break into smaller crystals by the pressing or squeezing action of the rollers. As the crystals pass through the rollers, they break into smaller crystals with a more even grain.

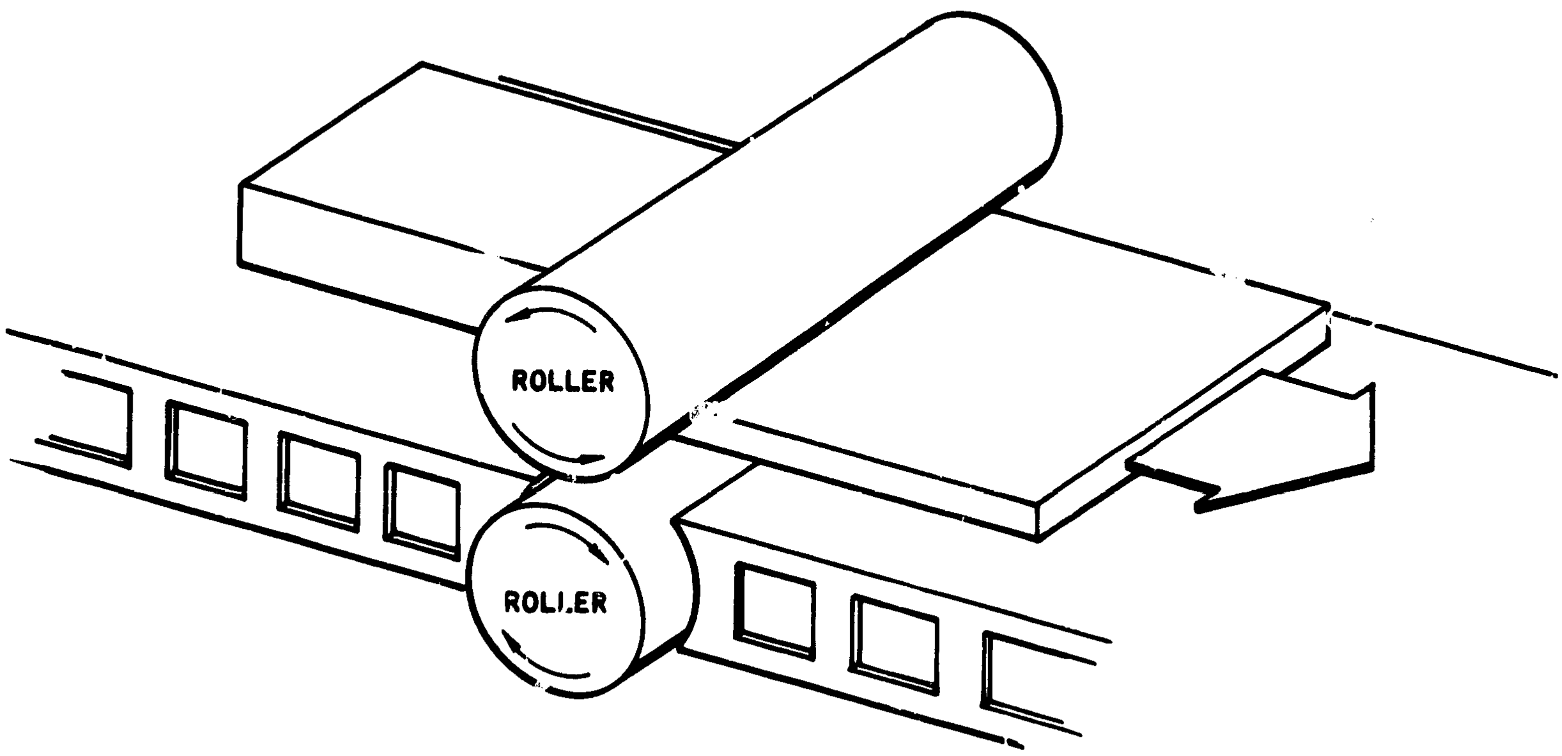
There you have it. Before rolling, the crystal grain in a billet is irregular. After rolling, this grain is more regular and it has direction--the direction in which it was rolled. If this metal were now cut in half, the grain would be visible to the naked eye.

Turn to page 2-3.

Good for you. The grain runs through the length of the bar. The grain will always run in THE DIRECTION OF ROLLING.

Now let's go back to the billet or slab and see what effect rolling has on the non-metallic inclusions. As you remember, non-metallic inclusions are pockets of foreign materials trapped in the hardened ingot. Most of the non-metallics are eliminated when the ingot is cropped but some remain in the billet or slab.

Here is a slab being rolled and the grain is formed in the direction of roll. The grain is formed when the crystals are broken and re-formed into small crystals which form the grain. Now let's see what happens to the non-metallic inclusions during rolling.

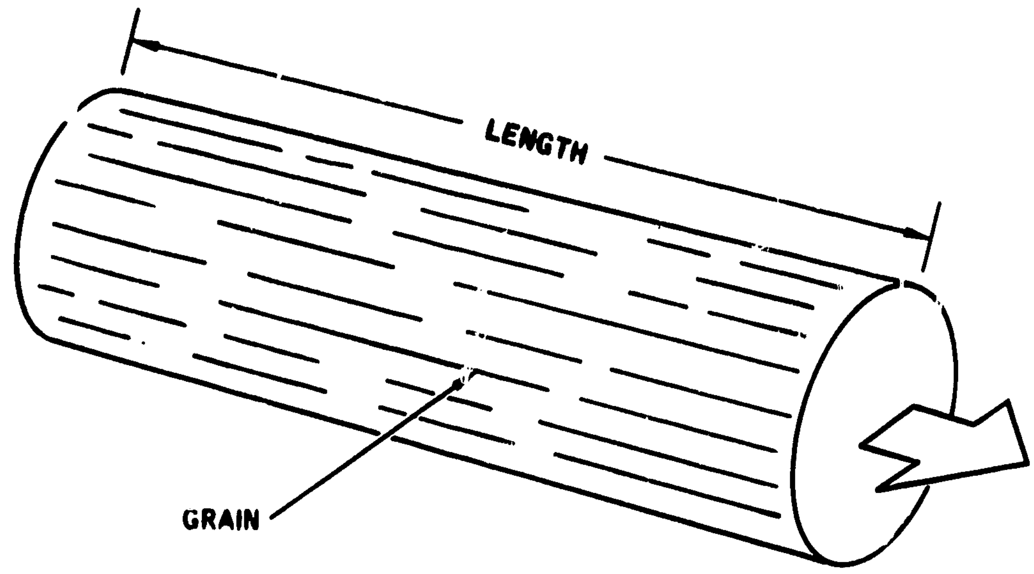


If the slab is to be rolled into sheet or plate material, it is rolled between wide, heavy rollers. These wide rollers reduce the slab thickness and increase its width and length. With this in mind, how do you think a non-metallic inclusion would act as it is pressed between the rollers?

It would spread in all directions but mainly in the direction of roll . . . . . . Page 2-7
It would spread out evenly in all directions . . . . Page 2-8

From page 2-3

You think the grain runs through the width of that rolled bar. Actually, the grain runs through the length of the rolled bar. Here is another illustration to make the point clear.



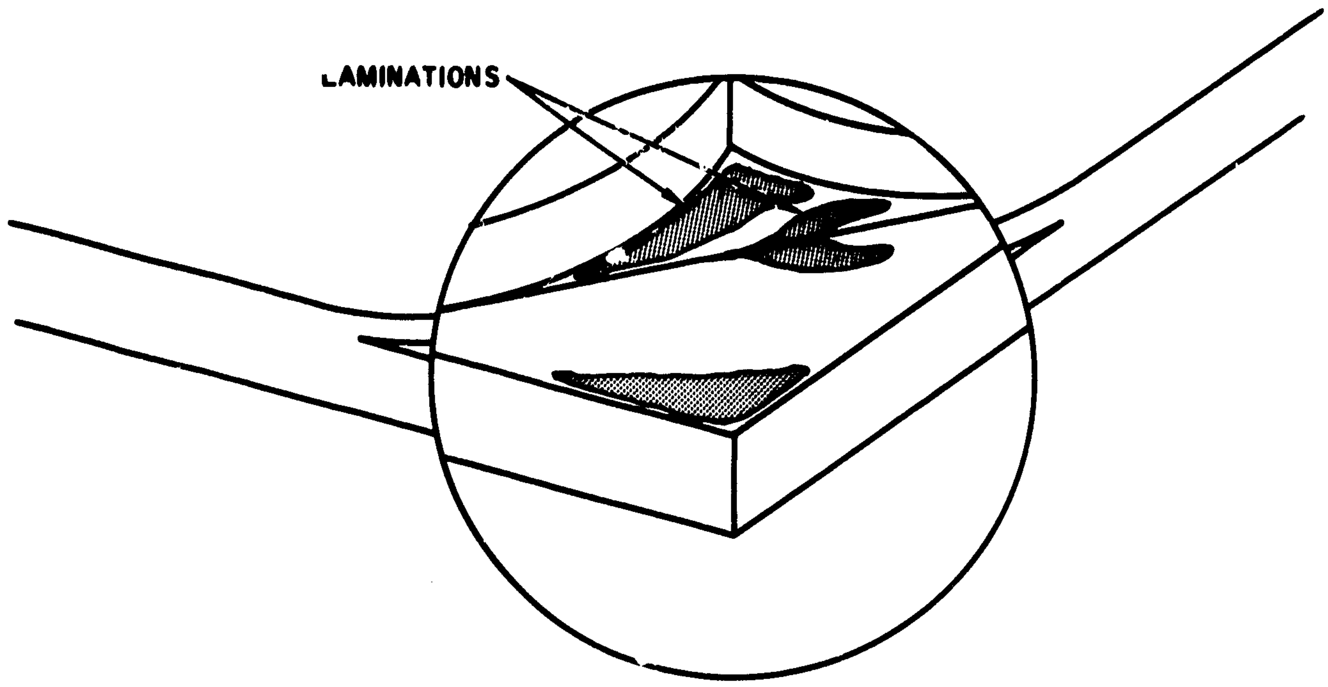
The width of the bar in this case is the diameter. Notice the lines which indicate the direction of grain. It runs through the length of the bar doesn't it?

Turn to page 2-5.

Right. A non-metallic inclusion would spread out in all directions but mainly in the DIRECTION OF ROLL.

As the slab is rolled thinner, longer, and wider, the non-metallic inclusion is flattened. This flattened inclusion is now called a LAMINATION.

A lamination is a non-metallic inclusion that is sandwiched in the steel.



Here you can see the laminations in the flattened condition. Notice also that they have been stretched in the direction of roll in the same manner as the crystal grain structure.

What do you think would happen to porosity in the slab being rolled into sheet or plate material?

Porosity would cause a lamination . . . . Page 2-9
Porosity would disappear. . . . . Page 2-10

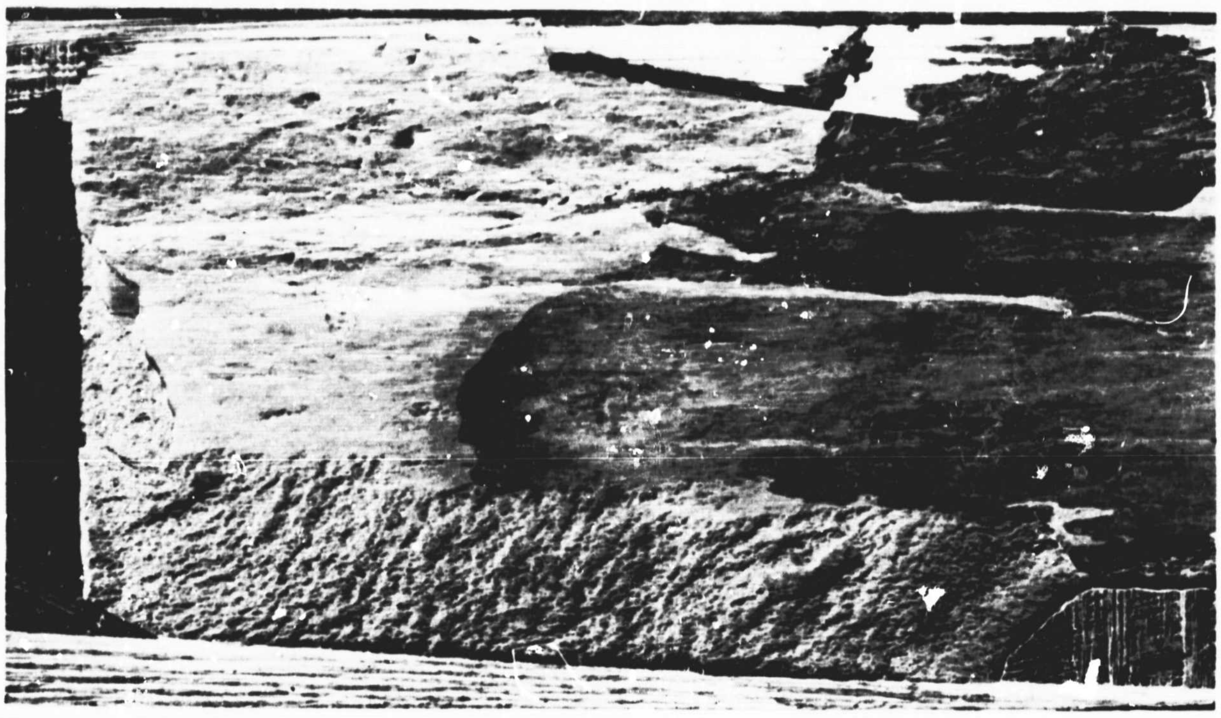
In your opinion a non-metallic inclusion in a slab being rolled into sheet or plate material would spread evenly in all directions. This is not the case. The inclusion spreads mainly in the direction of roll, but that is not the only direction in which it spreads. Let's see why.

When a slab is being flattened into sheet or plate, it becomes (through repeated rollings) longer, wider, thinner. It is being pressed forward much like pie dough under a rolling pin. The rolling flattens the inclusions in many directions although mainly in the direction of roll.

Return to page 2-5, re-read the last paragraph and choose the correct answer.

Yes sir. Porosity would cause a lamination. The gas porosity in the slab would spread out in all directions but mainly in the DIRECTION OF ROLL. It is possible that porosity could disappear in the rolling of some types of material like aluminum. This would depend upon the temperature of the material and the method or amount of rolling. In this case the metal would simply fuse or join due to the temperature and pressure applied in the rolling process. If the metal does not fuse, the porosity would cause a lamination.

Here is an actual lamination caused by a non-metallic inclusion. It was located in the center of a rolled piece of plate stock. To expose the inclusion, you can see by the saw marks, the plate was cut in half.



Here you can see that the non-metallic inclusion has been flattened and spread out but mainly in the direction of roll.

Pipe also causes lamination in rolled sheet or plate material. The squashing action of the rolling process flattens the pipe in the same way that porosity is flattened. Both are flattened or spread out in all directions but MAINLY IN THE DIRECTION OF ROLL.

Turn to page 2-11.

From page 2-7

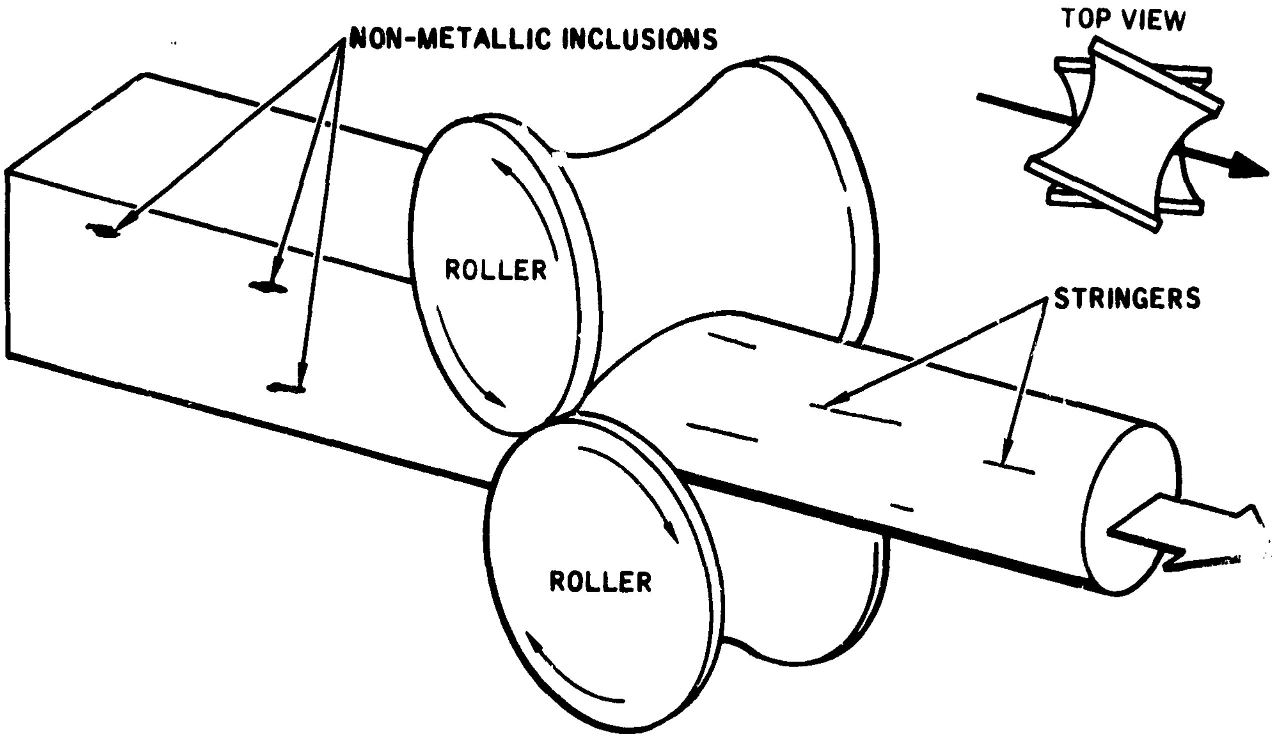
You think porosity would disappear in a slab rolled into sheet or plate material. Yes, that is true in some kinds of materials, which fuse or weld easily under proper temperature and pressure conditions.

What we are concerned with here, is the porosity which does not disappear. In this case, the round, bubble-like discontinuities are flattened when the slab is rolled. They spread out in all directions but mainly in the direction of rolling. Because of this, porosity will cause a lamination in much the same way that a non-metallic inclusion causes a lamination.

Return to page 2-9.

We have seen what happens to large porosity, pipe, and non-metallic inclusions in a slab being rolled into sheet or plate material--they flatten and spread out in all directions but mainly in the direction of roll. These flattened discontinuities are called LAMINATIONS. Now let us see how these discontinuities react when a billet is rolled into bar stock.

When the billet is rolled into bar stock, it is forced between rolls having an opening smaller than the size of the billet. The rolls have raised edges which are close together preventing the billet from being squeezed to the sides under the pressure. It can only roll forward and emerges smaller in diameter and longer.

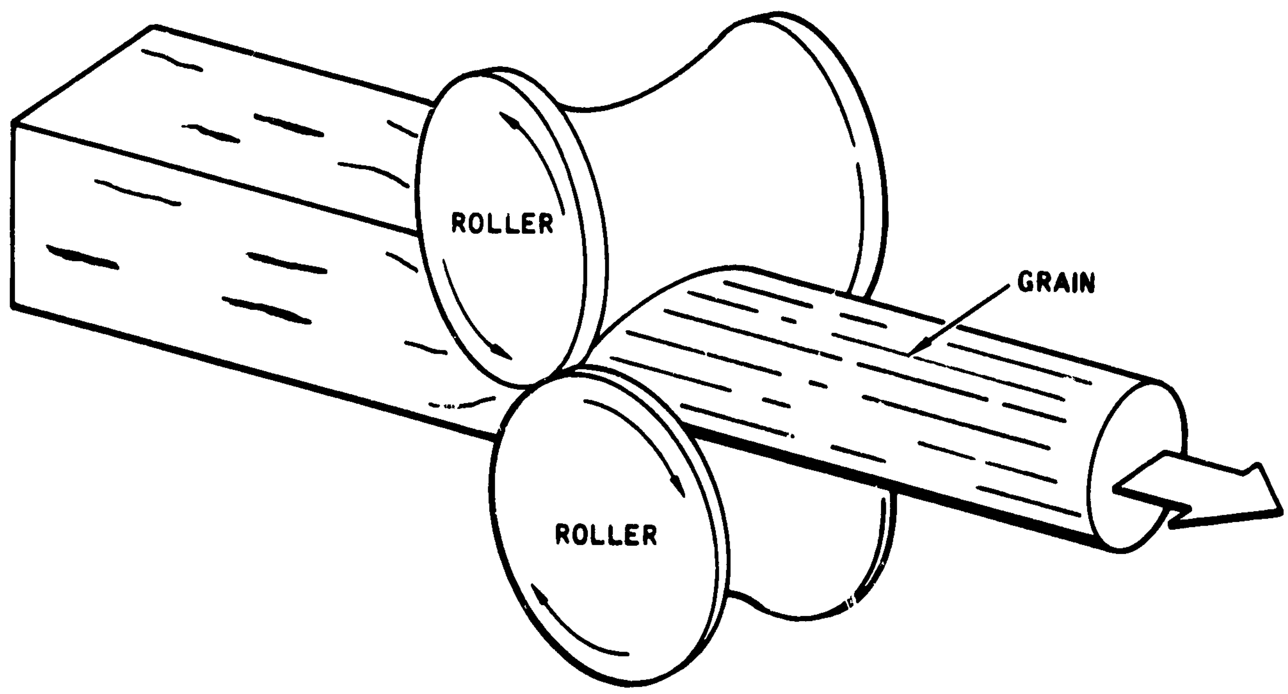


The longer the billet becomes, the longer and thinner the non-metallic inclusion becomes. The stretched out inclusion is now called a STRINGER.

Which of the following best describes how a non-metallic inclusion reacts in a billet being rolled into bar stock?

It spreads out like an egg in a frying pan . . . . Page 2-12
It extends in the direction of grain formation . . . . Page 2-13

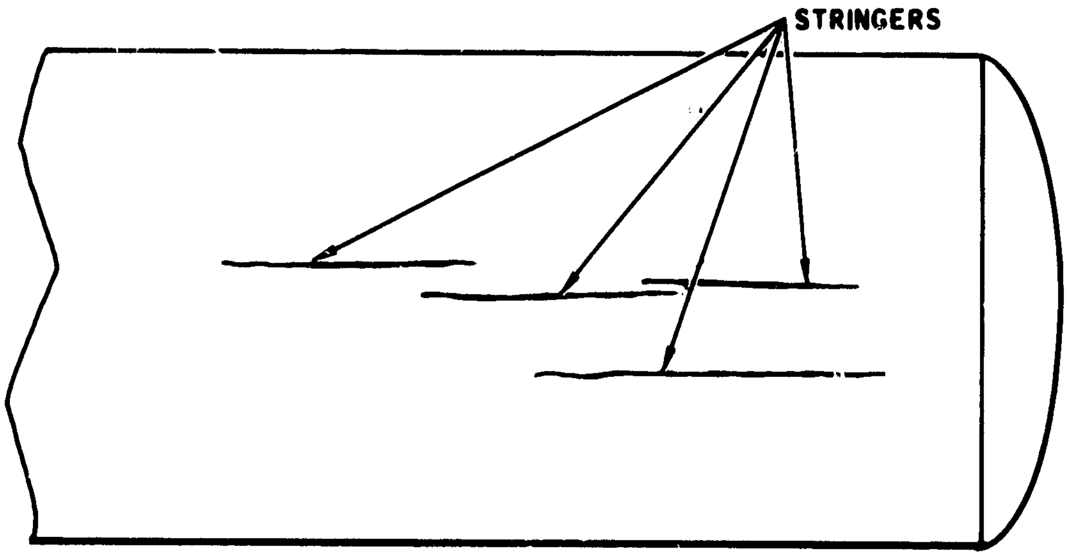
No, a non-metallic inclusion in bar stock does not spread out like an egg in a frying pan. You are thinking of a lamination--an inclusion in sheet or plate material spreads in many directions but mainly in the direction of rolling. Here, we are concerned with bar stock.



As the billet is rolled, it becomes longer and thinner. The crystal grain structure is broken up and reforms into finer grain with a definite direction--in the direction of roll as shown above. The pockets of slag or non-metallic inclusions are also stretched out in the direction of roll--they become longer and thinner as does the grain structure.

Turn to page 2-13.

Right. A non-metallic inclusion in bar stock extends in the direction of grain formation. As the billet is rolled smaller around and longer, the inclusion also becomes smaller around and longer. It is now called a STRINGER. A longitudinal cross-section of the bar would show how the stringer is stretched out like this.

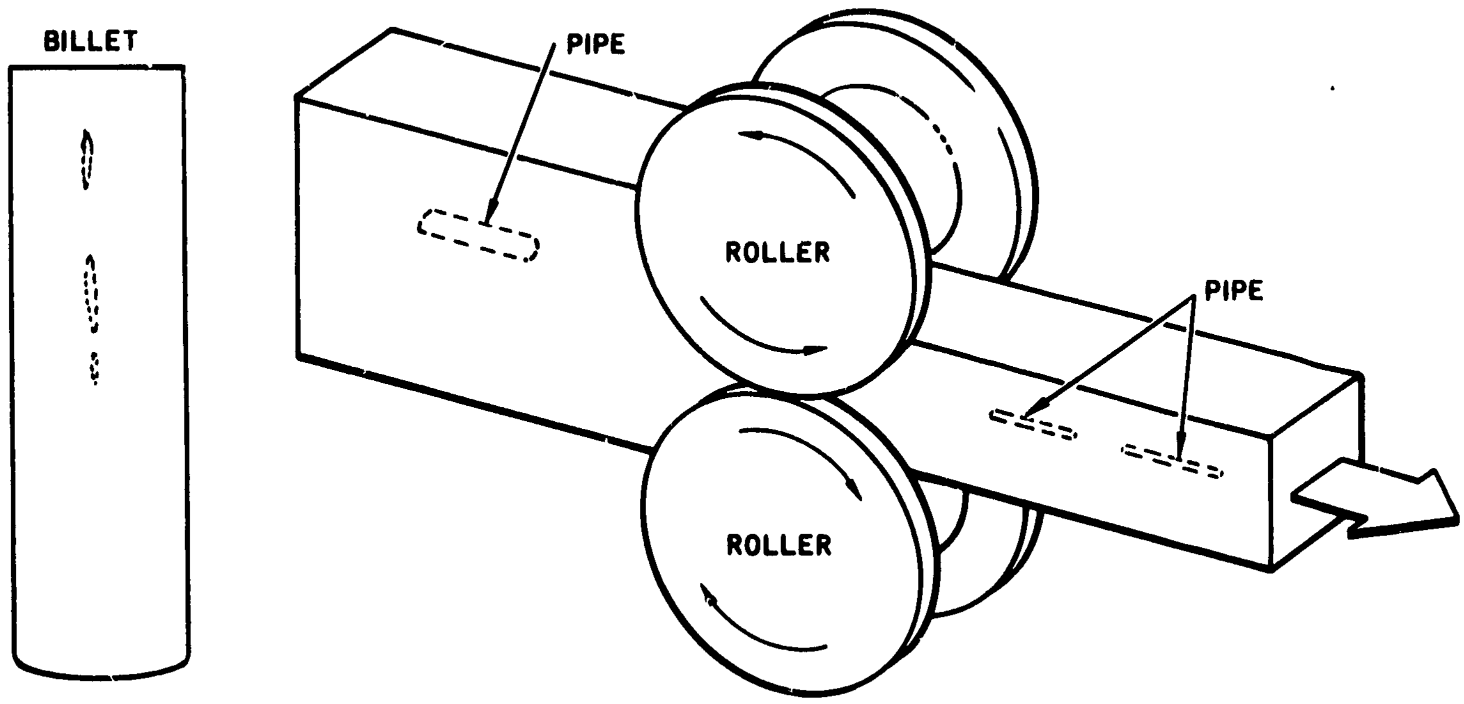


When a longitudinal cross-section of the bar is cut, porosity and pipe would show up stretched out in the same manner as the stringers. However, they would appear as intermittent cracks or elongated cavities.

Turn to page 2-14.

From page 2-13

Here you can see the shrinkage cavities or "pipe" in the billet. Notice how the pipe becomes smaller around and longer.



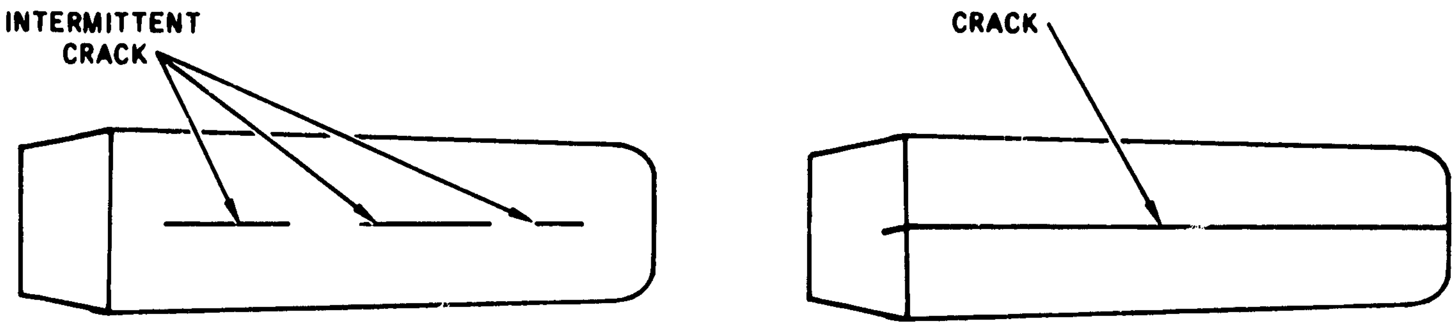
As the billet is rolled more and more, the pipe will continue to stretch out in the direction of roll. Pipe retains its name even in the elongated condition.

Turn to page 2-15.

From page 2-14

Up to this point, we have talked about discontinuities within the metal--non-metallic inclusions, porosity, and pipe. These are known as SUB-SURFACE discontinuities. Now let us discuss discontinuities on the surface of the billet and how they react to the rolling process.

First, let us discuss a common crack in the billet.



Like other discontinuities in the billet, the cracks get another name when the billet is rolled. As the billet is rolled and stretched out, so are the cracks. The crack or cracks are then called a SEAM. SEAMS are always open to the surface.

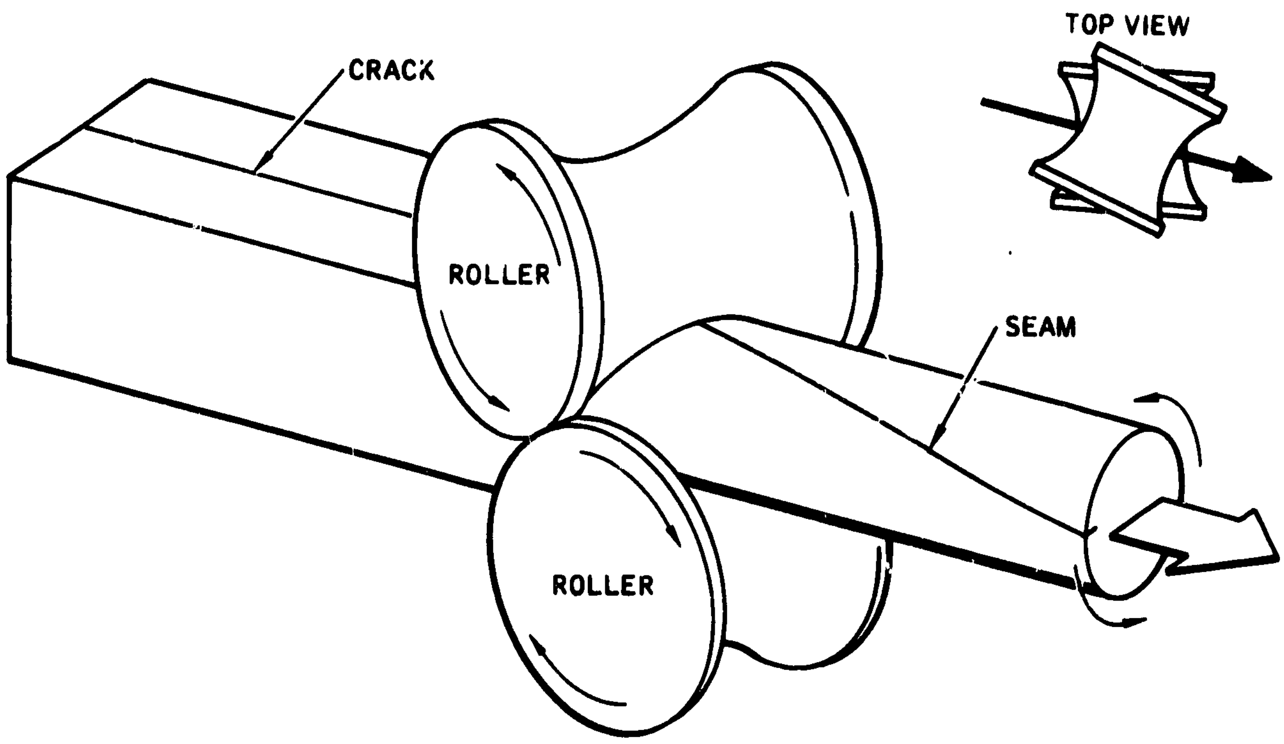
Do you think the seams (cracks) are discontinuities?

Yes . . . . Page 2-16

No . . . . Page 2-17

Of course! A seam is an INTERRUPTION IN THE NORMAL PHYSICAL STRUCTURE OF THE BILLET. Therefore, it is a discontinuity.

Seams are caused by surface cracks or irregularities on the ingot after it has been cast. Seams may also be caused by folding of the metal due to improper rolling or by a defect in the roller. As these discontinuities are rolled, they stretch out like taffy. This lengthens the SEAM in the direction of roll in the same way that non-metallic inclusions are stretched out.



When the billet is rolled into round bar stock, the seam may appear as a spiral in the bar. This is caused by the angular mating of the rolls (see top view) resulting in a turning of the material as it is rolled. The example is exaggerated, of course.

Which of the following states the relationship between the direction of the seam and the direction of grain flow?

The seam forms at an angle to the grain flow . . . . Page 2-18
The seam forms in the direction of grain flow . . . . Page 2-19

You don't think seams (cracks) in the billet are discontinuities. You must have forgotten the definition of a discontinuity so let's take a quick look at it.

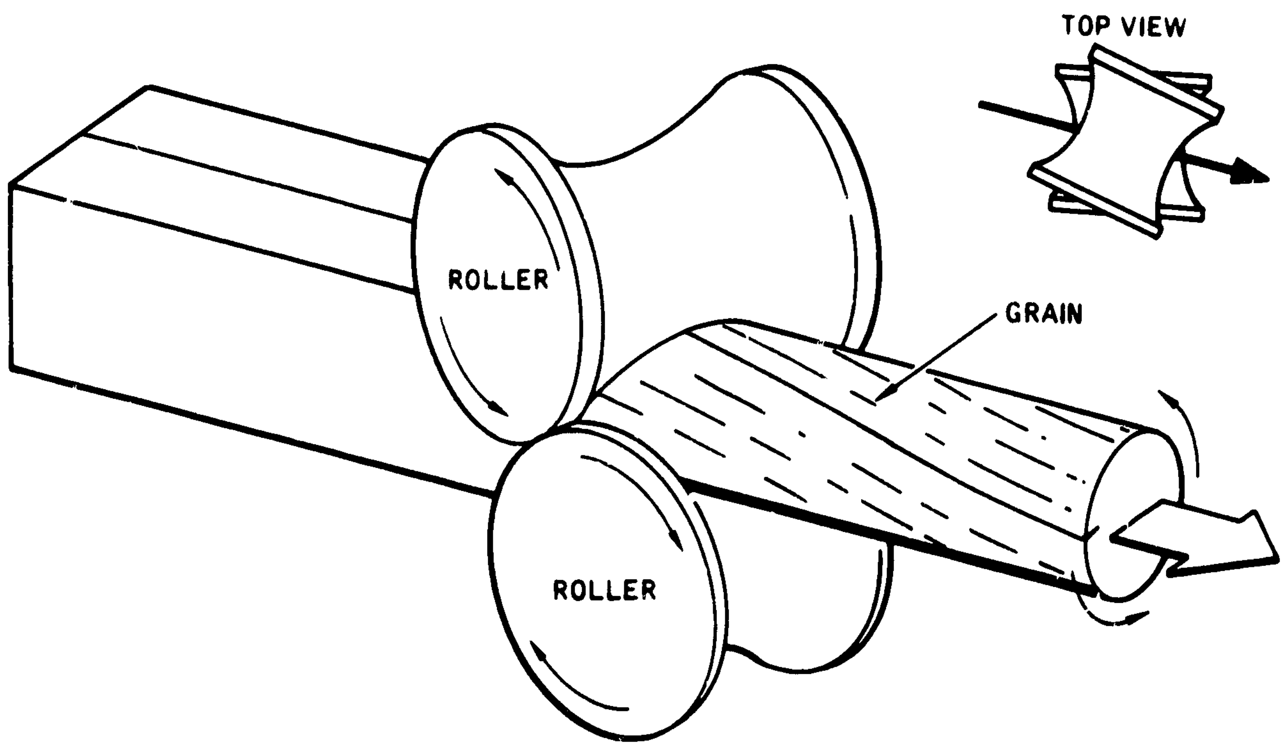
A DISCONTINUITY is defined as:

A BREAK OR INTERRUPTION IN THE NORMAL PHYSICAL STRUCTURE OF AN ARTICLE.

A crack in a billet is not supposed to be there. Cracks are caused by shrinkage as the molten metal solidifies. So you see, cracks or seams are interruptions in the normal physical structure of the billet and are, therefore, DISCONTINUITIES.

Turn to page 2-16.

You think the seam forms at an angle to the grain flow in that round bar. Actually, the turning tendency of the metal caused by the angular mating of the rolls will cause the grain to form in a spiral the same as the seam.

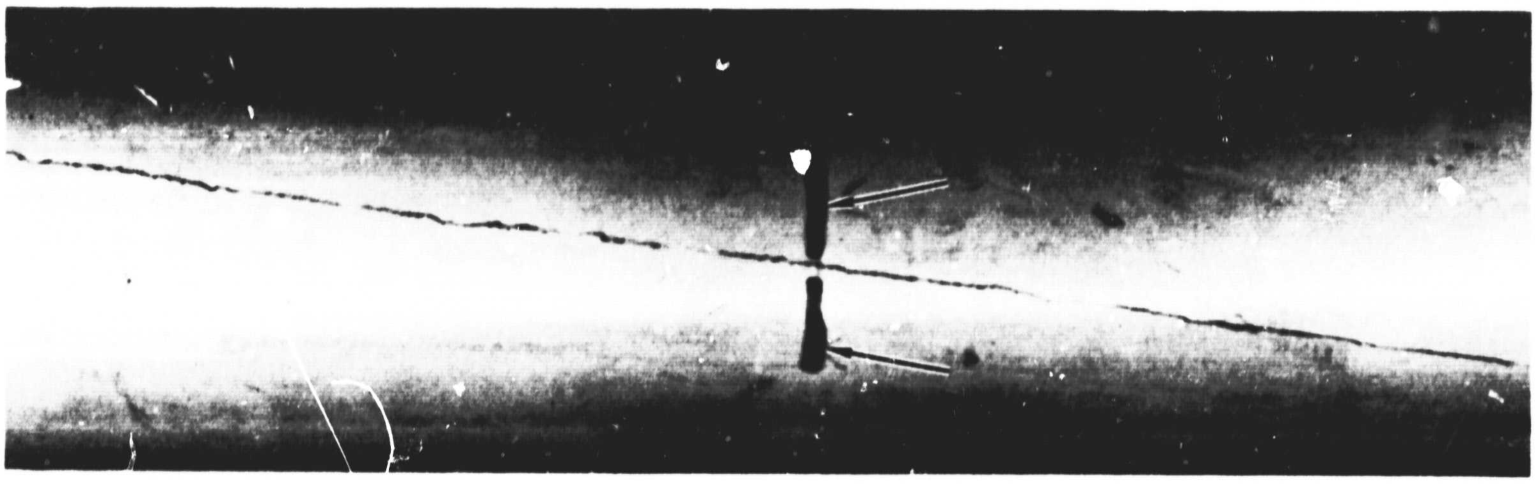


Remember, the illustration is exaggerated for the purpose of illustration. But as the billet is rolled and re-rolled, the spiral effect becomes more pronounced. But the seam does form in the same direction as the grain.

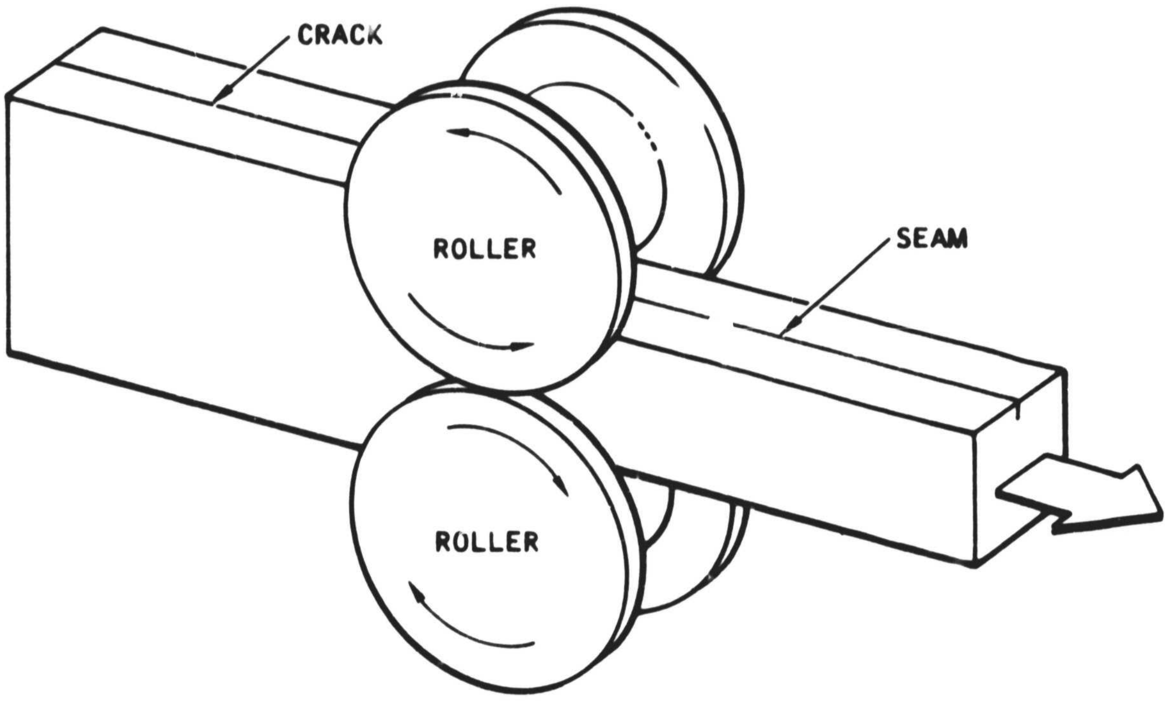
Turn to page 2-19.

From page 2-16

Good for you. The seam forms in the direction of grain flow. The angular mating of the rolls causes the material to turn and the grain as well as the seam will be formed as a spiral. Here is an example of a spiral seam in a round bar.



Now consider the cracked billet being rolled into bar stock.



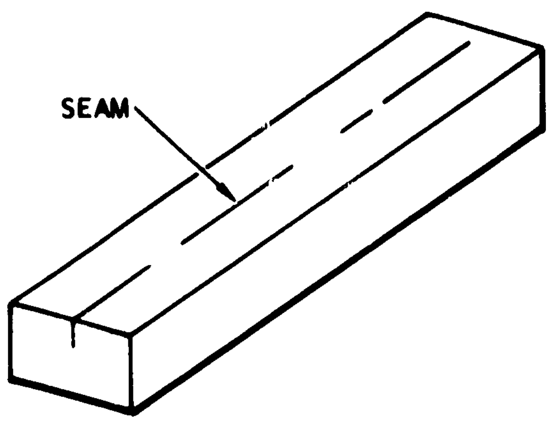
As you can see, a seam in the bar also stretches out in the direction of roll. Considering the seam in the round rolled bar at the top, and the seam in the rectangular bar, which of the following correctly states the direction of grain flow in both cases?

In the direction of the seam in both cases . . . . Page 2-20

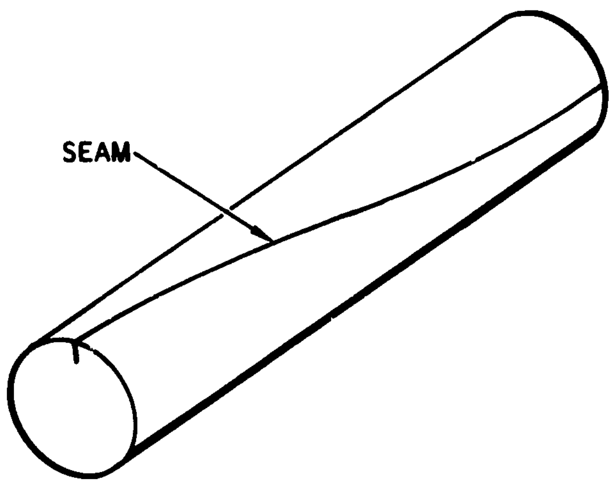
In the direction of the seam in the rectangular bar and through the length of the round bar . . . . Page 2-21

Absolutely. The grain flows in the direction of the seam in both cases. The more the bar is rolled, the longer the seam will extend.

On a finished bar, a seam may appear as either a continuous straight line or a series of straight lines following each other like this.



A seam in round bar stock, or tubing, also appears in a straight line or slight spiral which may be continuous or broken.



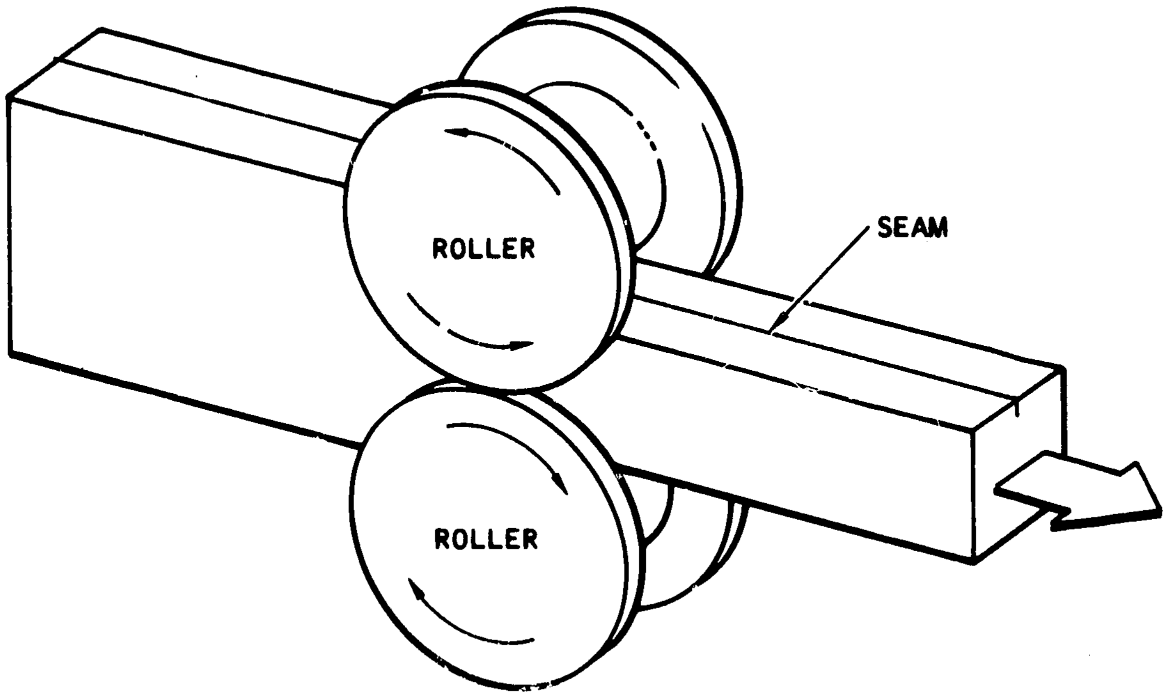
Any discontinuity will form in the direction of roll just as the grain does. The seam in the round bar had a slight spiral to it. The spiral is caused by the tendency of the rounded metal to spiral during rolling operations.

Which one of the following types of discontinuities would you most likely expect to find in a SHEET OF METAL?

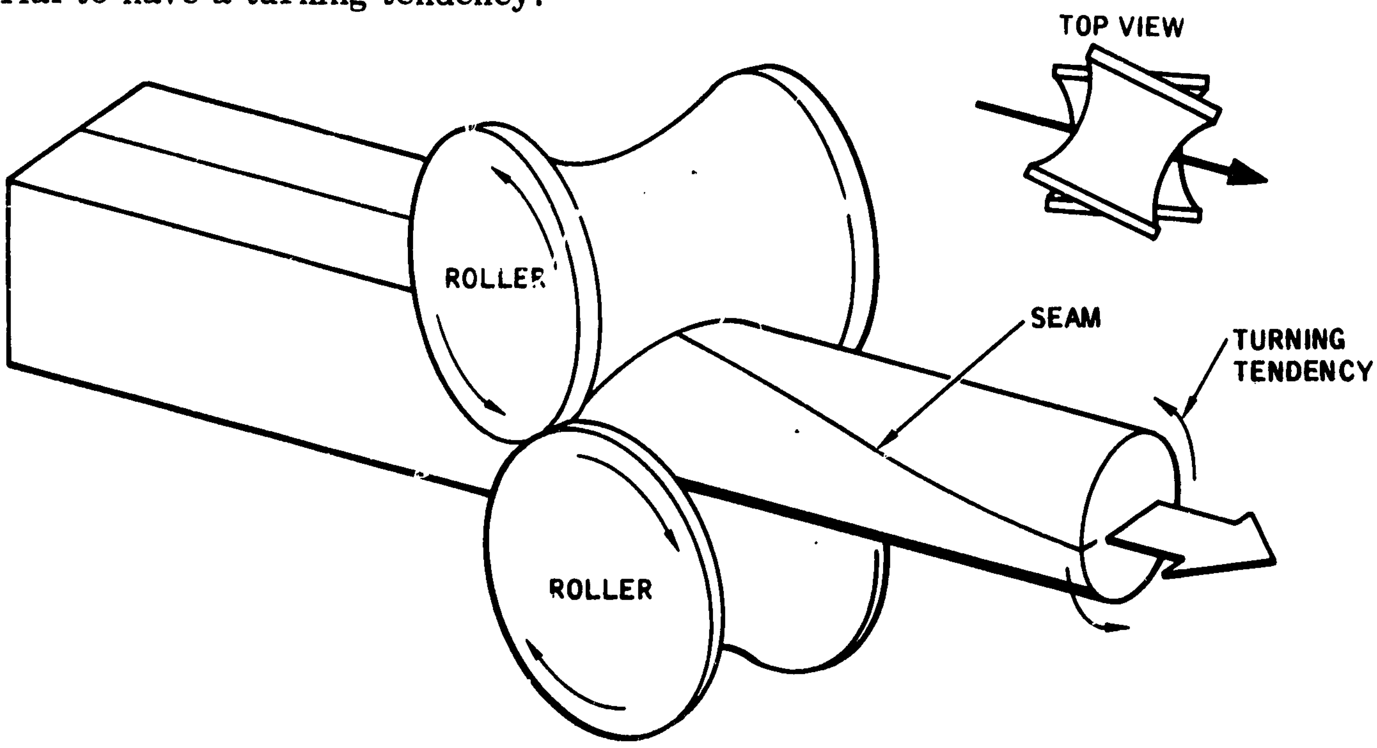
Seams . . . . Page 2-22
Laminations . . . . Page 2-23
Stringers . . . . Page 2-24

From page 2-19

You think the grain flows in the direction of the seam in the rectangular bar and through the length of the round bar. You are half right. The grain does flow in the direction of the seam in the rectangular bar.



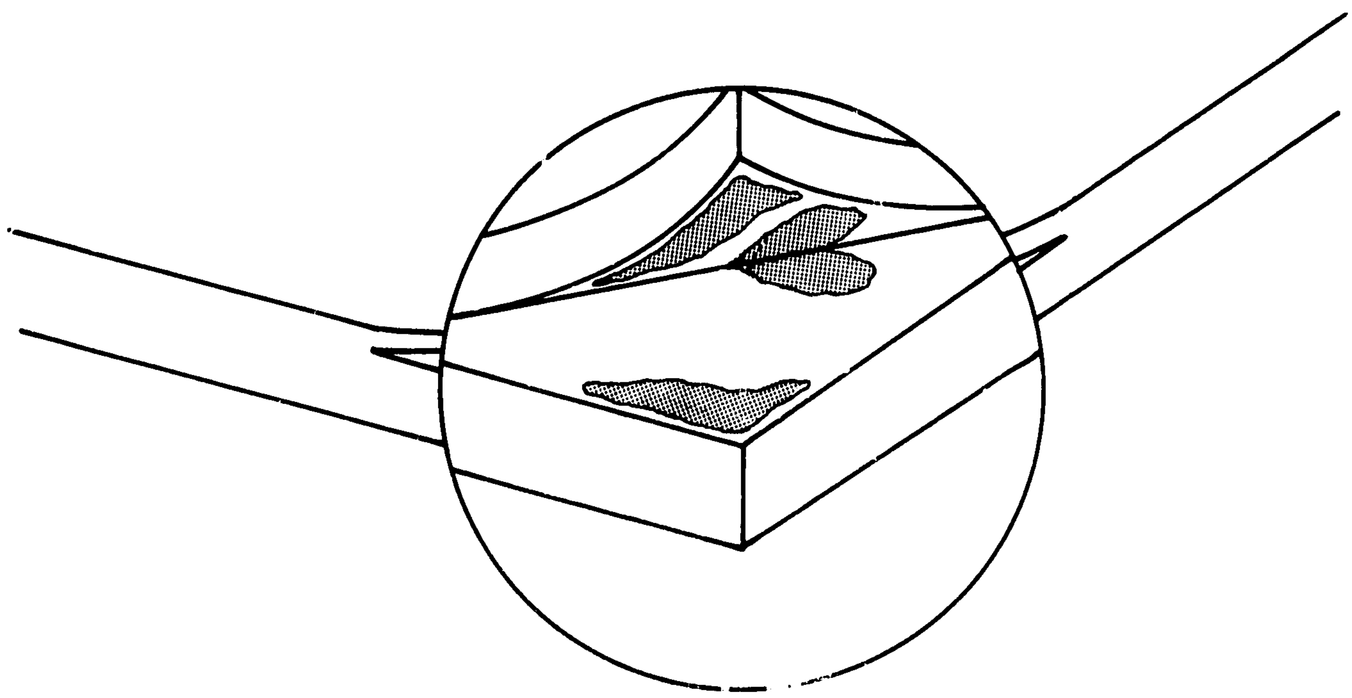
But when the billet is rolled into a round bar, both the seam and the grain form in a slight spiral. This is caused by the angular mating of the rolls which causes the material to have a turning tendency.



So you see, the grain flows in the direction of the seam in both cases.

Turn to page 2-20.

You would expect to find "seams" in a sheet of metal. Probably not. Seams are usually found in the surface of bar stock. See if this illustration won't give you a clue to the correct answer.

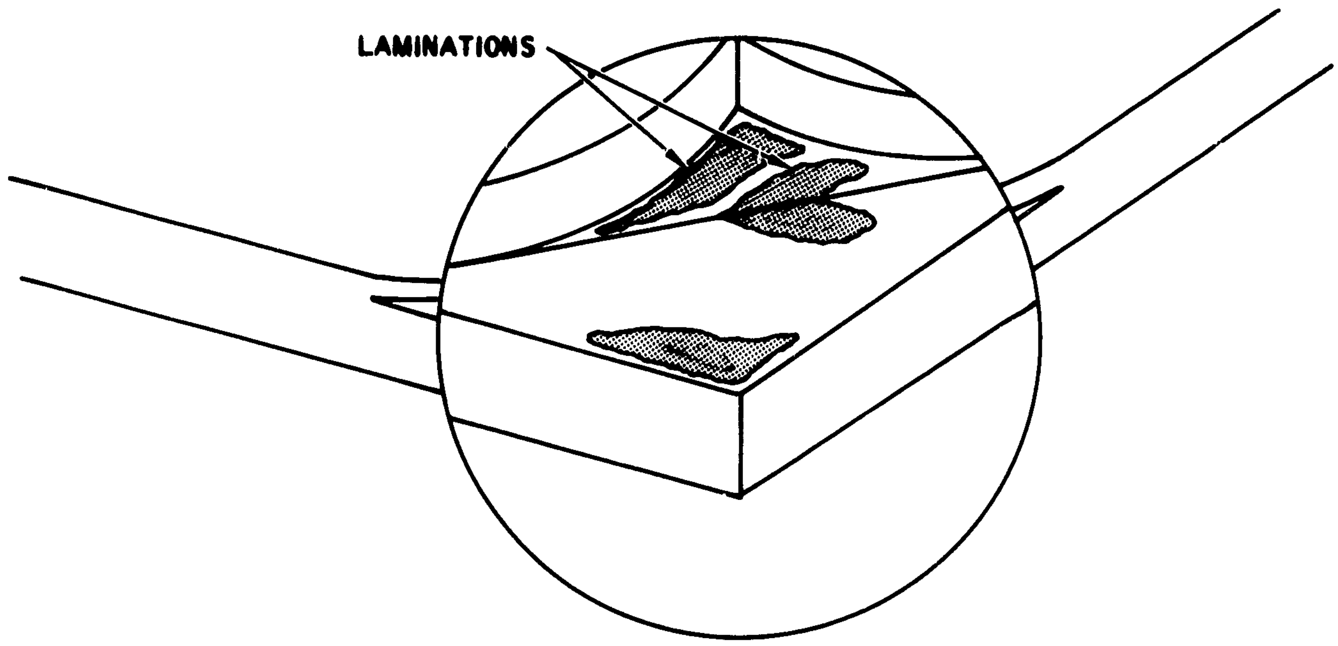


In a sheet of metal, you would expect to find non-metallic inclusions or gas porosity which have been flattened by rollers and which have spread out in all directions, but mainly in the direction of roll.

Return to page 2-20 and select the correct answer.

From page 2-20

Yes, of course. You would expect to find laminations in a sheet of metal. A lamination is simply a non-metallic inclusion that has been rolled or squashed and spreads out in many directions although mainly in the direction of roll. Of course, gas-bubble porosity will also cause laminations when rolled into sheet stock.



Seams and stringers are discontinuities which have been stretched out by rolling and are found in bar stock.

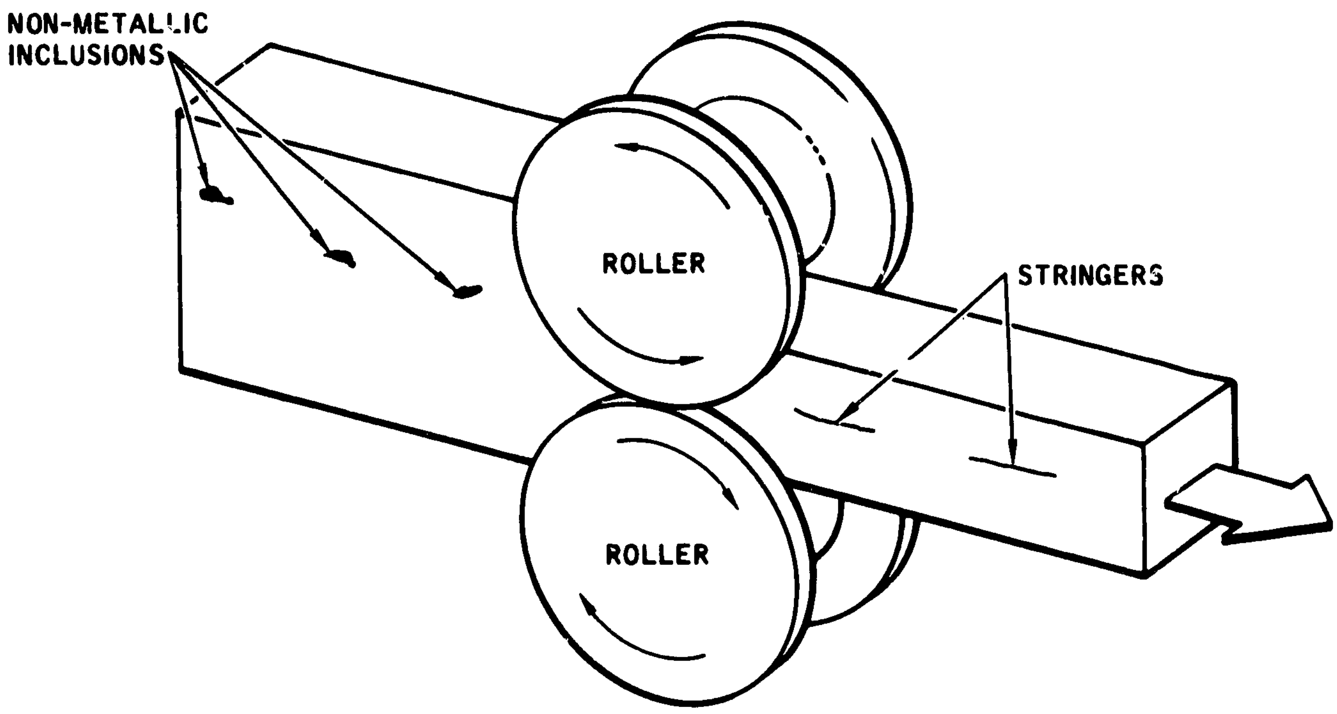
Before a billet is rolled into bar stock, it may contain foreign inclusions. When the billet is rolled into bar stock, the inclusions get another name. What is the inclusion then called?

Seams . . . . Page 2-25
Non-metallic inclusion . . . . Page 2-26
Stringer . . . . Page 2-27

From page 2-20

You would expect to find stringers in a sheet of metal. No, stringers would probably not be found in a sheet of metal and here is why.

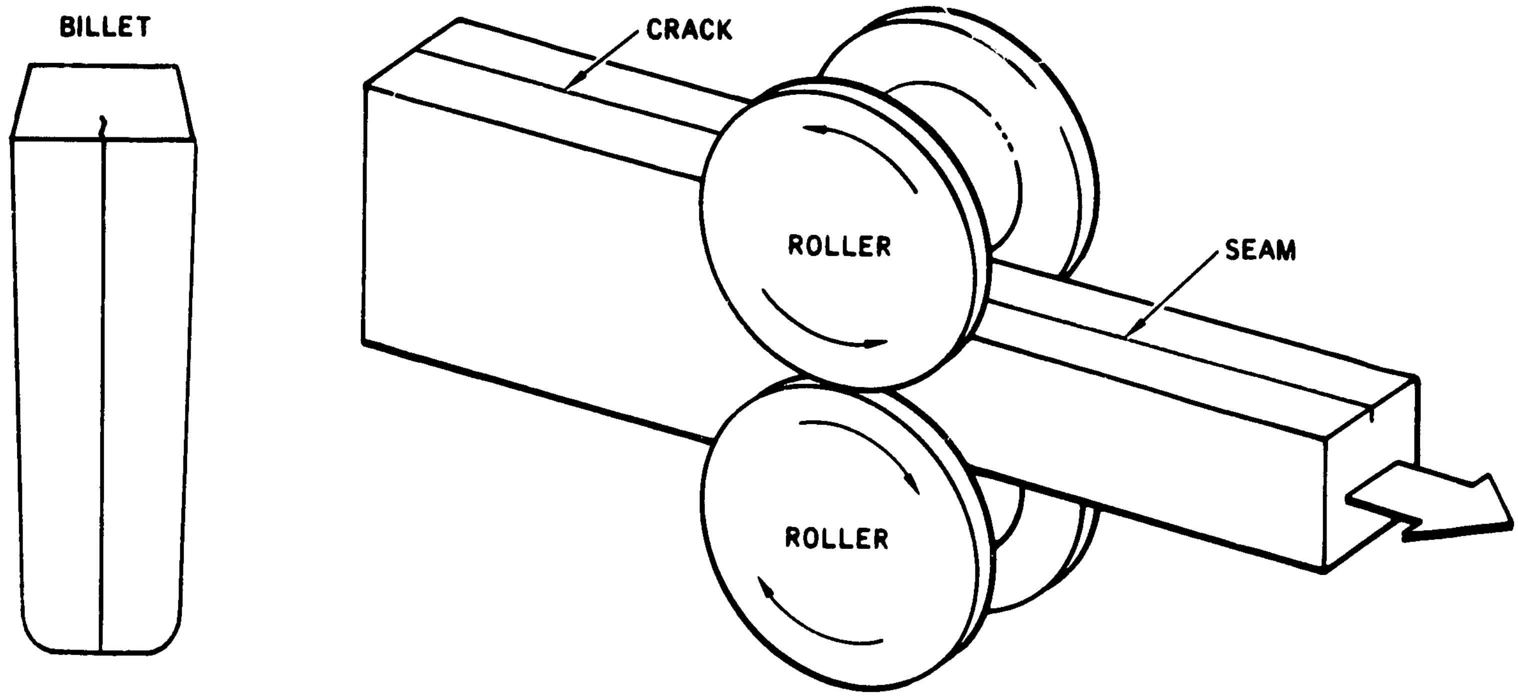
Stringers are formed in the rolling process from non-metallic inclusions in the billet. The inclusions are pockets of foreign materials in the billet. When the billet is rolled, the metal becomes smaller around and longer. The non-metallic inclusions are also squeezed and stretched out like taffy.



Here you can see how stringers are formed from non-metallic inclusions. The more times the bar is rolled, the longer and thinner the stringers become. In the processing of sheet materials, the rolling operation will tend to flatten rather than just elongate the inclusion. The result is a lamination rather than a stringer.

Return to page 2-20 and try again.

You think non-metallic inclusions in the billet are called seams after the billet is rolled into bar stock. No, seams are caused by cracks in the surface of the billet.

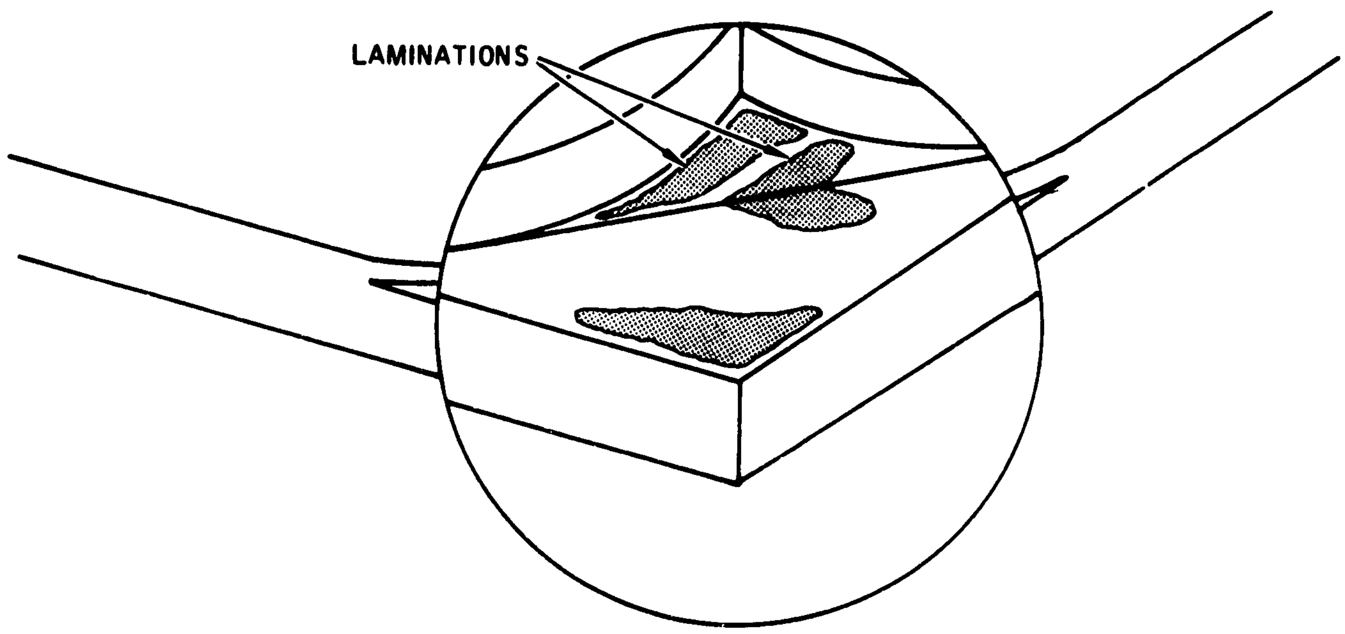


Another important fact here is that seams are always open to the surface. Non-metallic inclusions are inside the billet--they are sub-surface.

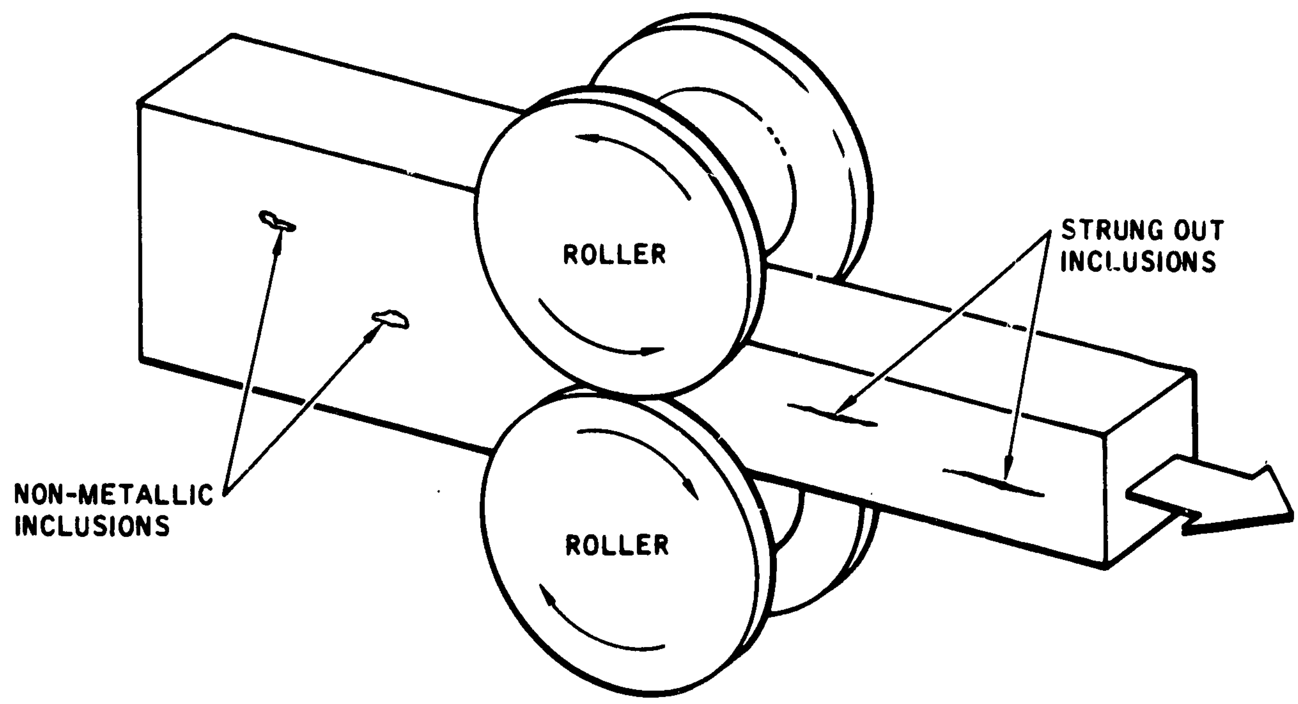
Return to page 2-23 and re-read the last paragraph again.

From page 2-23

You think non-metallic inclusions in the billet have the same name after the billet is rolled. Remember now, a non-metallic inclusion in the billet is an irregular shaped pocket of impurities. After the billet is rolled, the non-metallic inclusion is stretched out and becomes longer and thinner and forms in the direction of roll. In plate material, the inclusion is flattened out in all directions but mainly in the direction of roll. It is then called a LAMINATION.



In bar stock, the non-metallic inclusion is made longer and thinner.

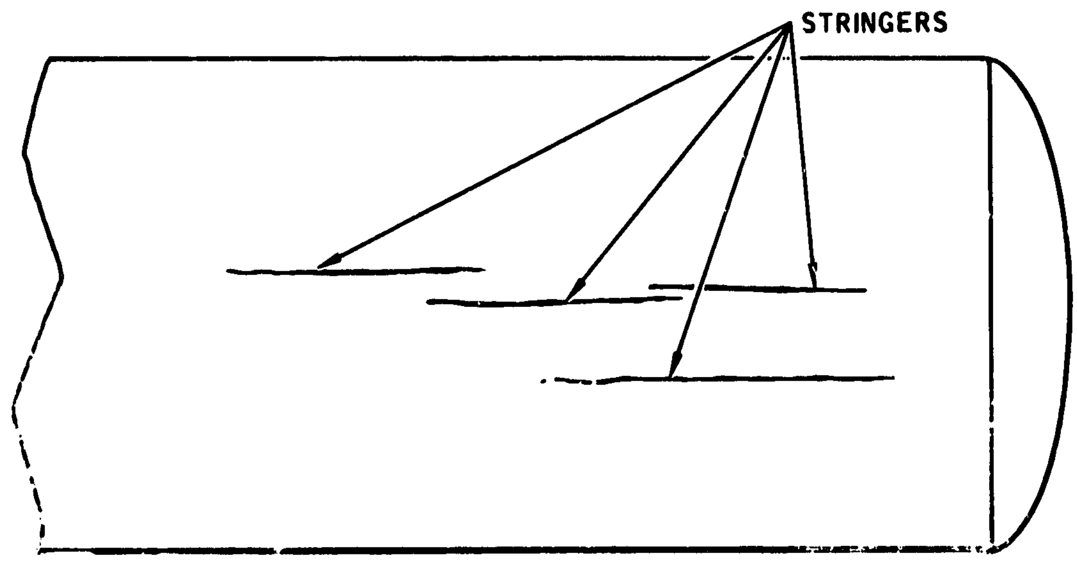


After being rolled, those non-metallic inclusions are strung out.

Return to page 2-23 and select the correct answer now.

From page 2-23

You are right. The non-metallic inclusion is called a stringer. Of course, the non-metallic material is still there but it is stretched out. In a cross-section of bar stock, the stringer would look like this.



Turn to the next page for a short review.

From page 2-27

1. It is important to remember that the cropped ingot or billet has a crystal grain structure. In the billet, the grain (has/has no) ____________ direction.

4. porosity

5. When the slab is rolled into sheet or plate stock, non-metallic inclusions are flattened but spread mainly in the __________________ of roll.

8. roll

9. Pipe and gas-bubble porosity also form laminations when the billet is rolled into sheet or ____________ stock.

12. billet

13. When the billet is rolled and stretched out, any cracks in the billet are also stretched out. The cracks are then called a s_________.

1. has no

2. Working or rolling of the billet, breaks the grain structure down. The grain becomes finer and begins to have d____________________.

5. direction

6. These inclusions are sandwiched in the flattened-out metal and are called lam____________________.

9. plate

10. When the billet is rolled into bar stock, the shrinkage cavities become smaller around and longer and are called p__________.

13. seam

14. Seams are always open to the____________________.

2. direction

3. The grain forms in the direction the metal is r____________.

6. laminations

7. When the billet is made into bar stock, the non-metallic inclusions are stretched out like taffy and are called str________________.

10. pipe

11. Since non-metallic inclusions, porosity, and pipe are found in the metal, they are sub-surface dis__________________.

14. surface

15. Seams also form in the direction of __________ flow.

3. rolled

4. Before the billet is rolled, it may have discontinuities in the metal such as non-metallic inclusions, pipe, and gas p______________.

Return to page 2-28, frame 5.

7. stringers

8. Stringers--stretched-out inclusions--form in the direction of __________ just as does the grain.

Return to page 2-28, frame 9.

11. discontinuities

12. Surface discontinuities (open to the surface) originate from surface irregularities or cracks in the b_____________.

Return to page 2-28, frame 13.

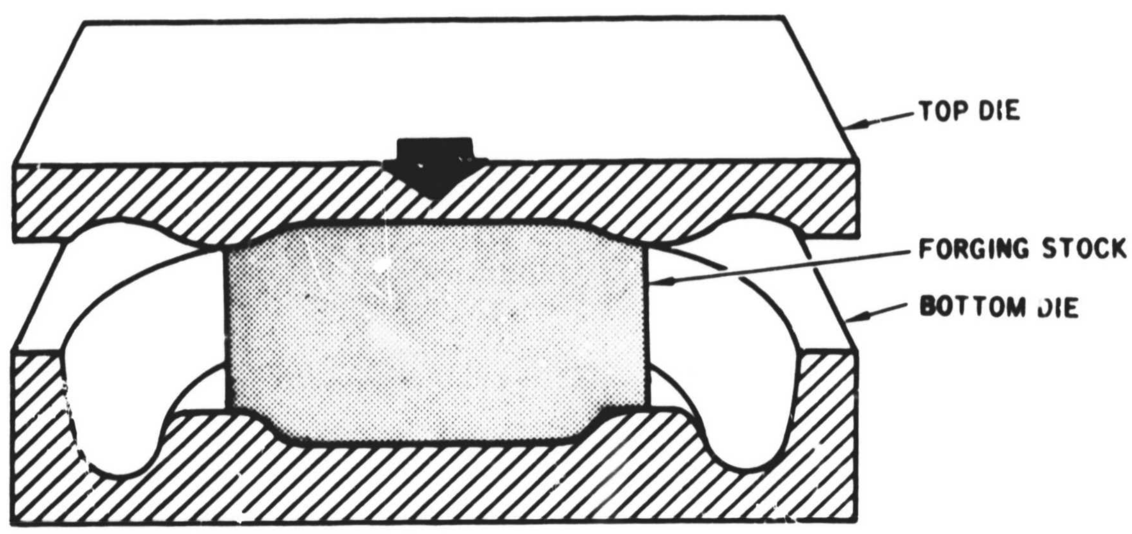
15. grain

Turn to page 3-1.

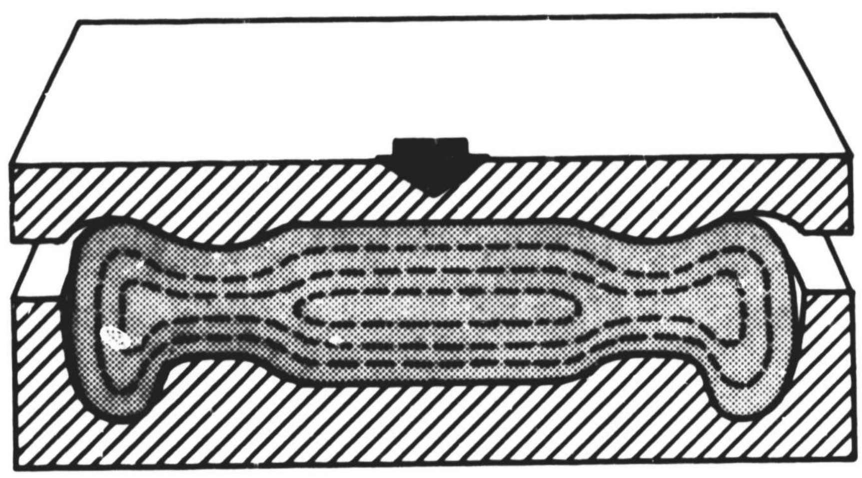
In the previous section, we discussed working of the slab or billet and the effects the forming process has on grain structure and discontinuities. In this section, we are going to discuss another metal forming process called forging.

Forging is the working of metal into a desired shape by hammering or pressing the metal while it is very hot and in a soft condition. Since some discontinuities are caused by the forging process itself, let's take a brief look at the forging process.

The forging process starts with forging stock. These drawings are sliced down the middle so you will be able to see what goes on inside.



CROSS-SECTION



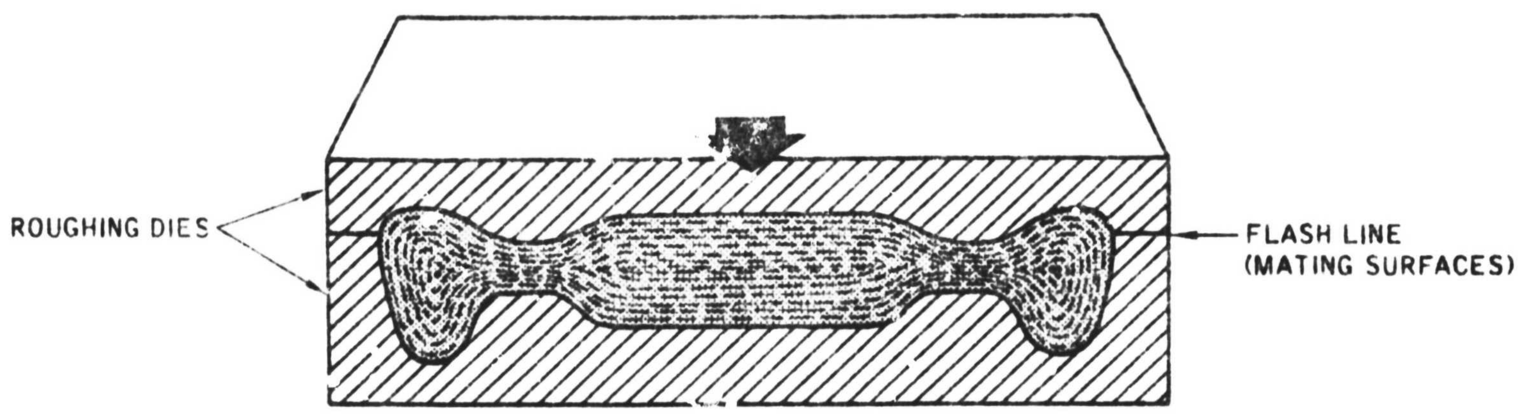
Turn to the next page.

From page 3-1

The forging operation uses two dies. The billet is gradually heated to forging temperature (heat soaked) then placed between the two dies. The forging press or hammer then squeezes or pounds the hot metal between the two dies. Forging the metal breaks the crystal grain structure down to form finer grain just as in rolling operations.

The forging process takes several steps.

The first step is to squeeze or hammer the billet into a roughing die. This gives the metal a rough shape of the desired article. Here you can see the hot metal is rough-shaped from being squeezed or pounded between the dies.

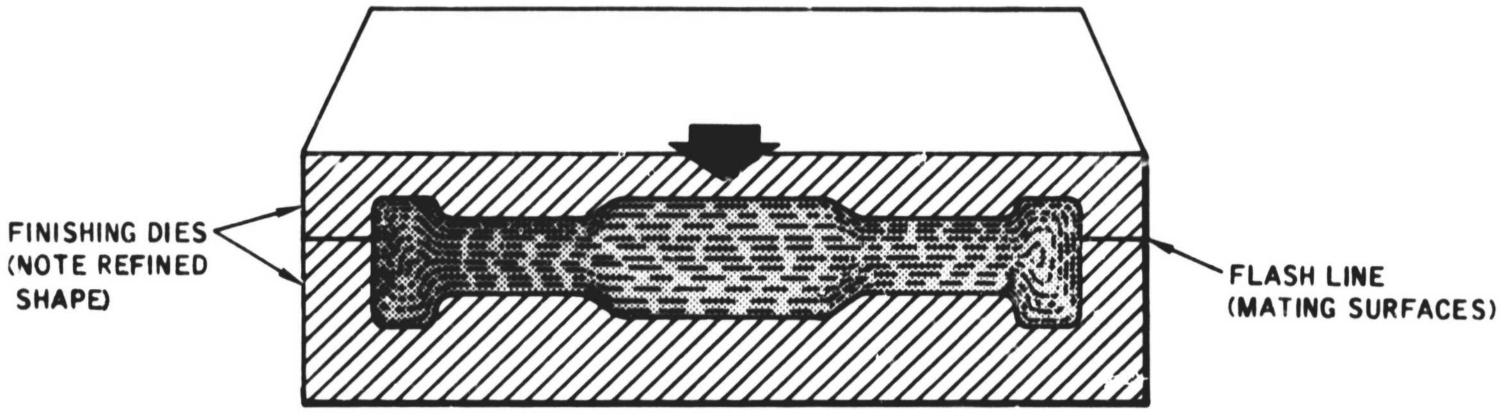


Working the metal by hammering it into the two dies, breaks the crystal grain structure down into finer grain. The grain follows the form of the dies in the same manner as rolling operations where the grain follows the direction of roll.

After the metal is rough-shaped, it is placed in a finishing die and is hammered into a more refined version of the same shape. What do you think happens to the grain?

The grain will follow the more refined shape . . . . Page 3-3
The grain will remain the same . . . . Page 3-4

That's right. The grain will follow the more refined shape. The more the metal is worked, the finer the grain will become. And the grain will follow the shape into which the object is being made.



SECOND FORGING

In summary then, the forging metal is placed in the lower die. The upper die is then brought down in repeated blows--each blow making a change in shape of the forging. The impact and pressure causes the metal to fill the die.

Grain flow of the metal undergoes a similar change into a repetition of the shape of the forging contours. The greatest value of this characteristic is that the grain flow lines remain unbroken and the forging is unified into a continuous structure, strong and tough throughout.

What is the main advantage of the grain flow lines in a forging?

The grain flow lines make a piece of metal easier to forge . . . . Page 3-5

The grain flow lines provide strength . . . . Page 3-6

From page 3-2

You believe the grain of a metal part forged in a finishing die retains the same flow as it had during the rough forging stage. That's not exactly so.

Working metal by hammering it between two dies breaks the cyrstal grain structure down into finer grain whether the dies are roughing dies or finishing dies. And, as the grain is broken down, it follows the form of the finishing die.

Turn to page 3-3

You believe that the main advantage of grain flow lines is to make a piece of metal easier to forge. That's not the answer we were looking for.

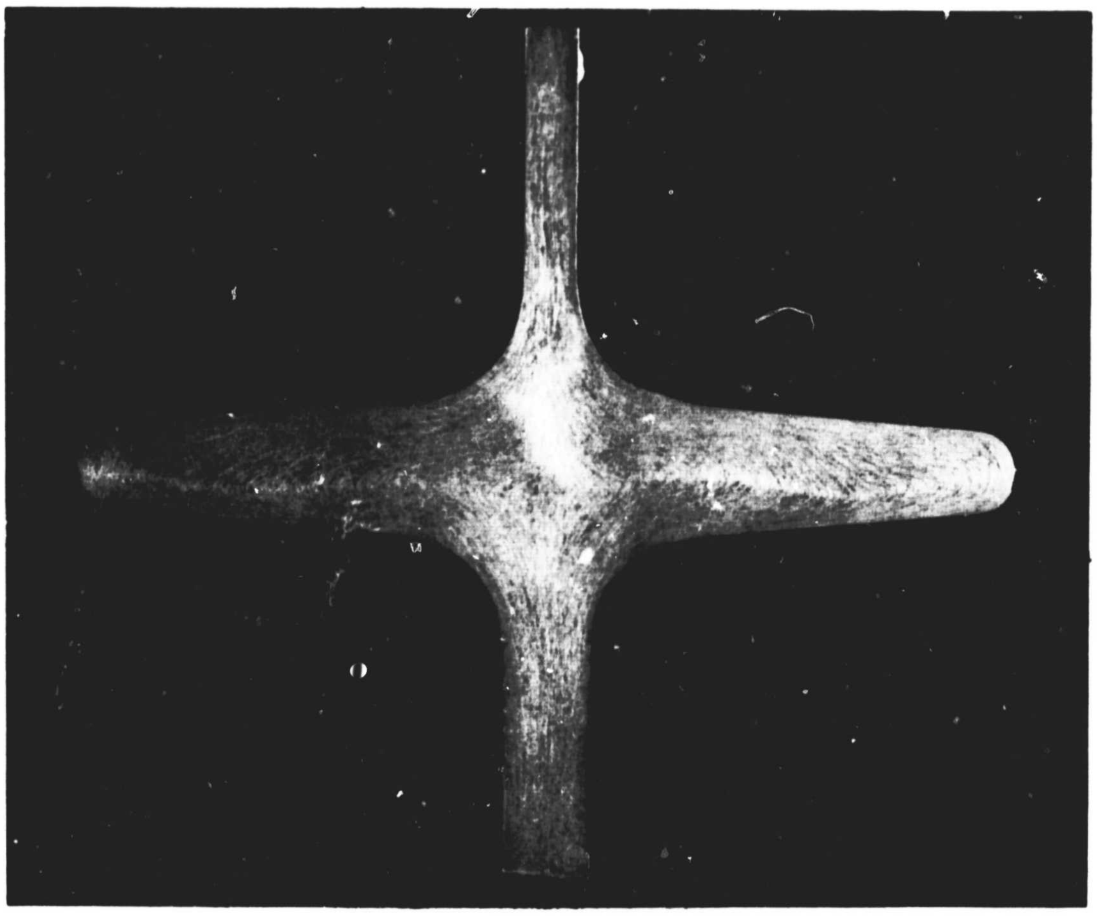
As metal is forged, the grain structure conforms to the shape of the object being formed. The grain flow lines remain unbroken as the metal is forged. In this manner, the metal forms a unified, continuous structure that is consistently strong throughout. Therefore, we would say that the main advantage of the grain flow lines is that they . . .

. . . provide strength . . . . Page 3-6

From page 3-3

Absolutely. The grain flow lines provide strength to the forging. Since the grain flow lines remain unbroken, the forging is unified into a continuous structure which is strong and tough.

Here is a photograph of the grain flow lines in a cross section of a forging.



These are grain flow lines in an aluminum forging.

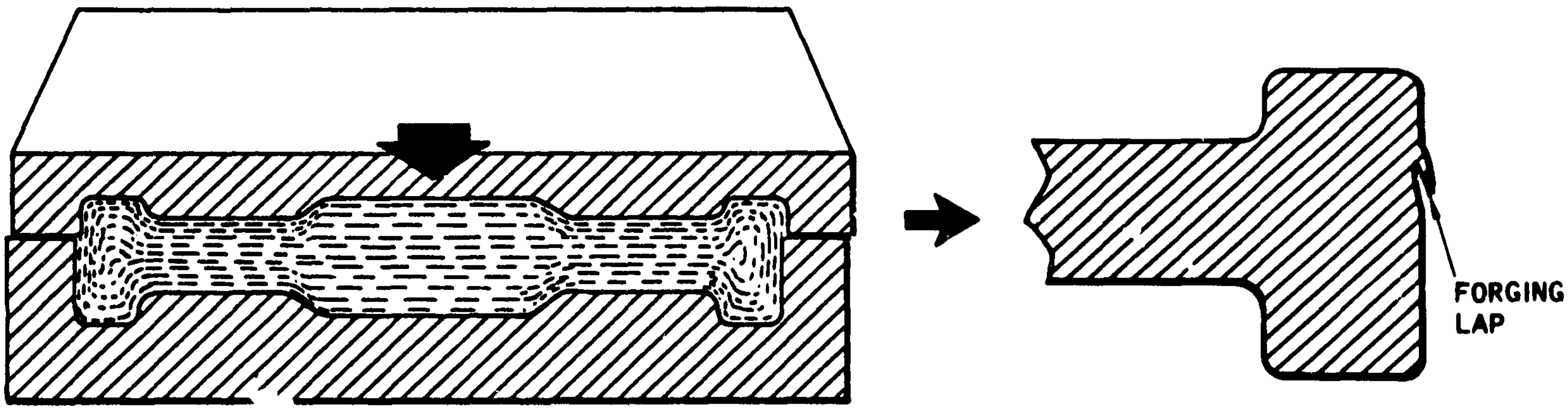
There are two primary types of discontinuities formed as a result of forging:

FORGING LAPS and

FORGING BURSTS OR CRACKS

Turn to the next page.

A <u>FORGING LAP</u> IS A DISCONTINUITY CAUSED BY FOLDING OF METAL IN A THIN PLATE ON THE SURFACE OF THE FORGING. One type of forging lap is caused when the mating surfaces of the two forging dies do not match.



As the forging stock is squeezed down between the two dies, some of the metal will be forced out between the mating surface. As the metal is further squeezed down, the metal will be sheared and folded up into a lap on the surface of the forging.

Since the forging lap is caused by a faulty die, do you think that it is ALWAYS open to the surface?

NO . . . . Page 3-8

YES . . . . Page 3-9

From page 3-7

Actually, the answer was yes. Let's take another look at the definition of a forging lap.

> A FORGING LAP IS A DISCONTINUITY CAUSED BY FOLDING OF METAL IN A THIN PLATE ON THE <u>SURFACE</u> OF THE FORGING.

Forging laps are always open to the surface.

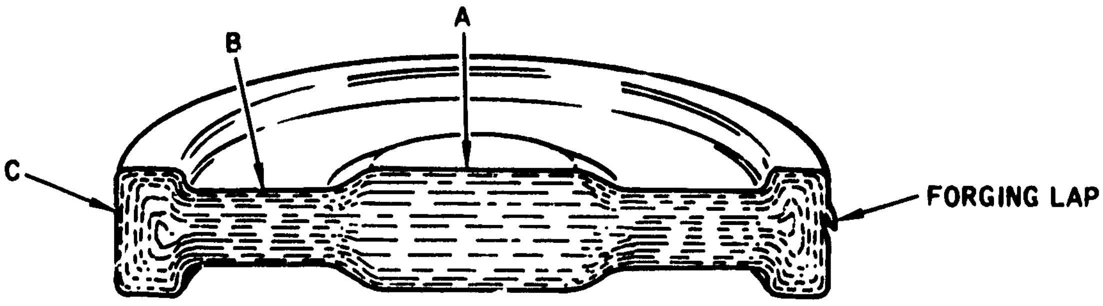
Turn to page 3-9

From page 3-7

Yes, of course. Forging laps are always open to the surface. And they may be found at the point where the two dies come together. Let's take another look at the definition of a lap.

A FORGING LAP IS A DISCONTINUITY CAUSED BY FOLDING OF METAL IN A THIN PLATE ON THE SURFACE OF THE FORGING.

Here is our forging taken out of the die. It has been cut in half so you can see the inside of the forging.



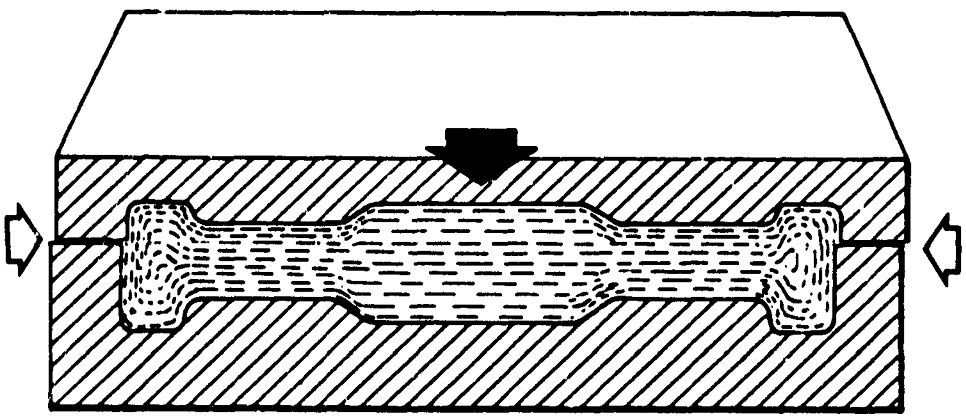
Since the forging lap shown above was made at the mating surface of the two forging dies, where else on the forging would there be another forging lap of this type (points A, B, or C)?

A . . . . Page 3-10
B . . . . Page 3-11
C . . . . Page . -12

You feel that another forging lap would be located at point A. Evidently we haven't made the point clear. Let's take another look at the problem. First, here is the definition to consider.

A FORGING LAP IS A DISCONTINUITY CAUSED BY FOLDING OF METAL IN A THIN PLATE ON THE SURFACE OF THE FORGING.

Now, here is our forging in the dies again.



There are only two places where the dies come together. One on the right and one on the left.

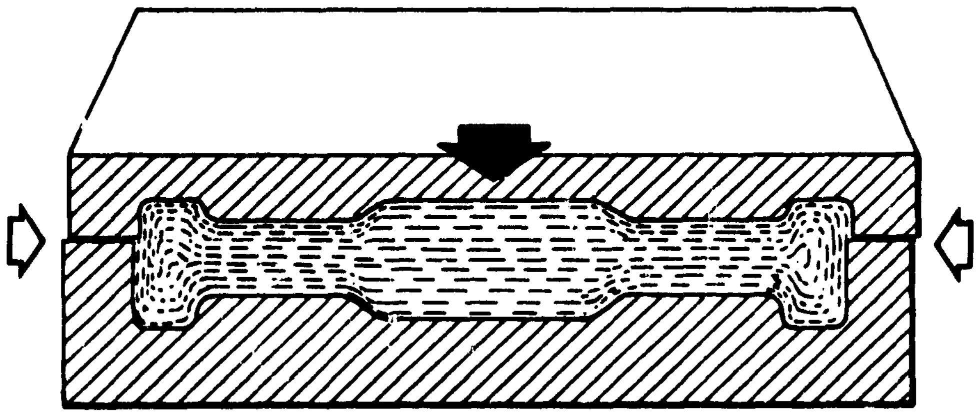
Return to page 3-9 and select another alternative.

From page 3-9

You selected B and that's not quite it. Let's take another look at this thing. First, here is the definition of a forging lap.

A FORGING LAP IS A DISCONTINUITY CAUSED BY FOLDING OF METAL IN A THIN PLATE ON THE SURFACE OF THE FORGING.

Now, let's take another look at our forging in the dies.

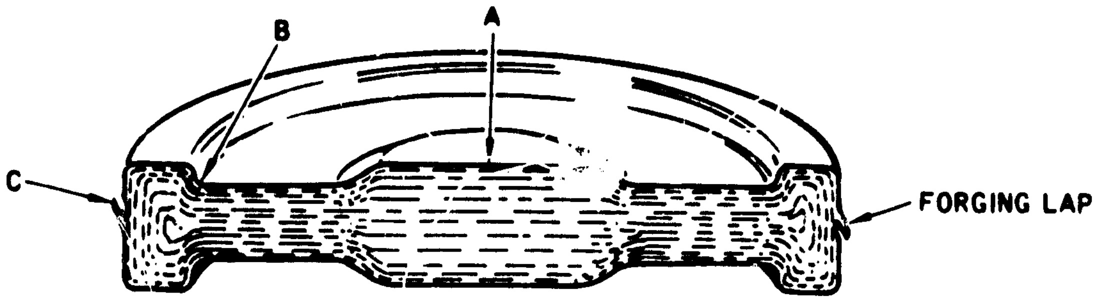


There are only two places where the dies come together as mating surfaces to cause a lap. One is on the right and the other on the left.

Return to page 3-9 and try another answer.

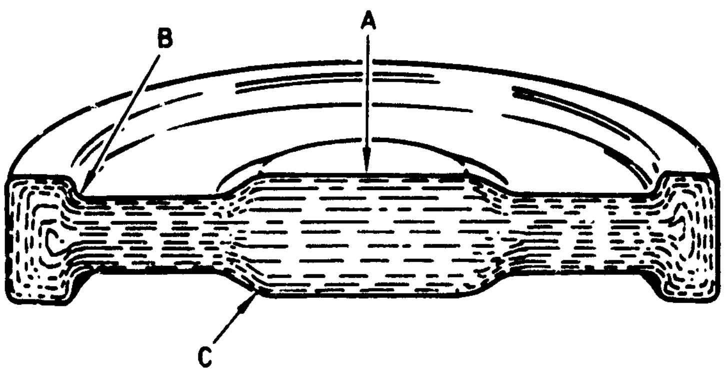
From page 3-9

Right. Another forging lap could be found at point C.



Point C is the other point where the two forging dies come together. The forging lap will always be open to the surface.

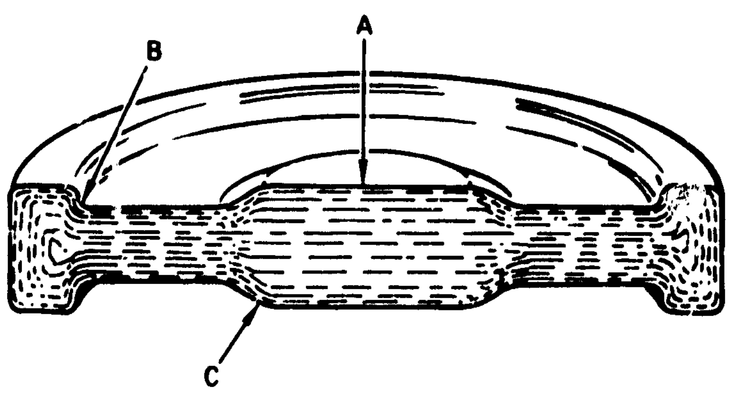
Another type of forging lap is formed in a forging at points where there is an abrupt change in grain direction. Here is our forging showing grain structure. At which of the following points on the forging is the most abrupt change in grain direction shown?



A . . . . Page 3-13
B . . . . Page 3-14
C . . . . Page 3-15

From page 3-12

You selected A and that is incorrect. You see, there is no abrupt change in grain direction at point A.

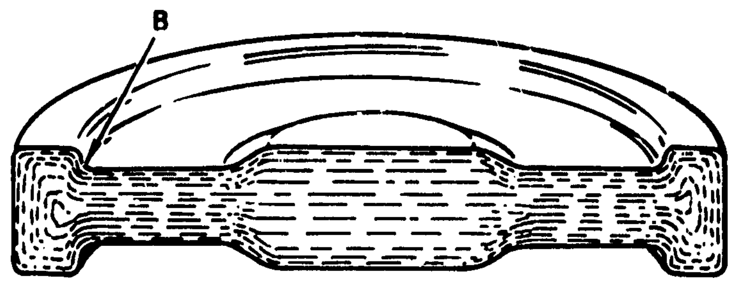


At point C, the grain does have some change in direction but it is not very abrupt. Grain direction changes are most abrupt where there is a sharp change in the profile of the forged object.

Return to page 3-12 and try again.

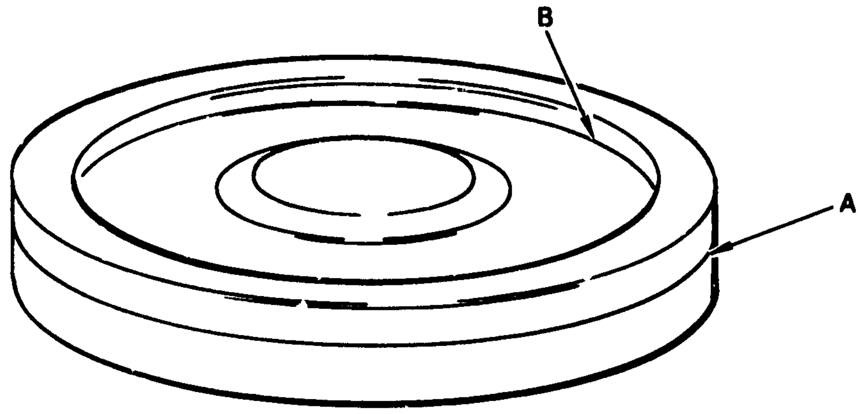
From page 3-12

Good for you. The most abrupt change in grain direction was shown at point B.



A forging lap is most likely to occur where the grain makes the most abrupt change in direction. At the points where the grain makes the most abrupt change in direction, the grains are also close together.

So far, we have shown only a cutaway view of this forged part. We have been forging a gear blank. Here is what the complete part looks like.



Which point, A or B in the picture, is the place where a forging lap may be caused by the mating surface of the two forging dies?

A . . . . Page 3-16

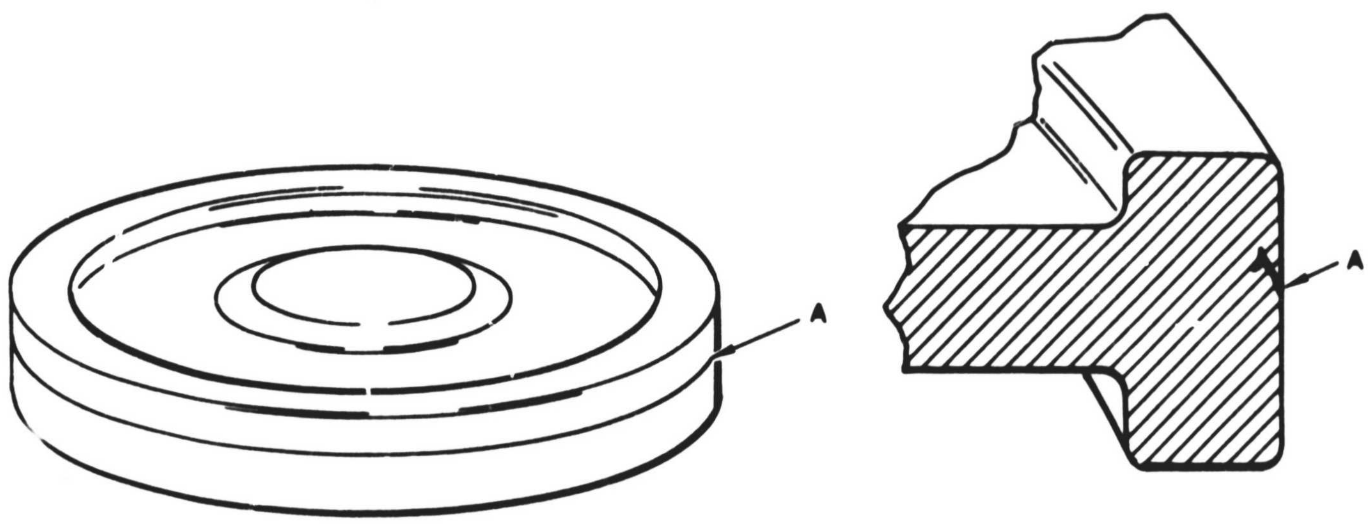
B . . . . Page 3-17

You selected C. It is evident that you are getting the idea. There is some change in grain direction at point C but it is not very abrupt. Therefore, it would be very unlikely to cause a forging lap at that point in the forging.

Return to page 3-12 and try once again.

From page 3-14

Right. Point A is the place where a forging lap may be caused by the mating surfaces of the two forging dies.

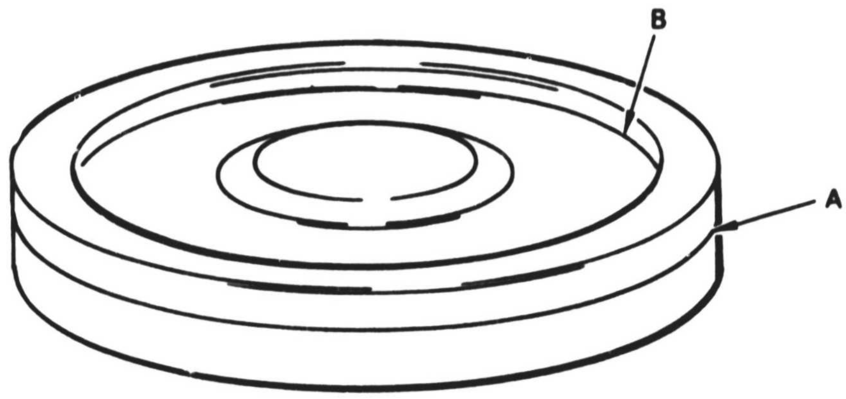


Now, before we go on, select the statement below which is the definition of a forging lap.

A FORGING LAP IS A DISCONTINUITY CAUSED BY FOLDING OF METAL IN A THIN PLATE WITHIN THE METAL FORGING .... Page 3-18

A FORGING LAP IS A DISCONTINUITY CAUSED BY FOLDING OF METAL IN A THIN PLATE ON THE SURFACE OF THE FORGING ...... Page 3-19

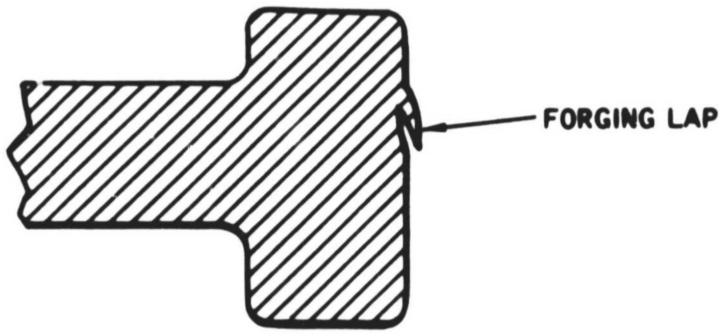
You are correct inasmuch as a forging lap can occur at point B due to an abrupt change in grain direction.



At point B, the two dies do not come together so a forging lap caused by the mating surfaces is not possible. In the case of our forging, there are only two points where the dies come together and that is at point A.

Turn to page 3-16.

You selected-- A FORGING LAP IS A DISCONTINUITY CAUSED BY FOLDING OF METAL IN A THIN PLATE WITHIN THE METAL FORGING. Let's take a look at a forging lap.



Actually, you can see that the forging lap is open to the surface. In fact, all forging laps are open to the surface. Here is the correct definition of a forging lap.

> A FORGING LAP IS A DISCONTINUITY CAUSED BY FOLDING OF METAL IN A THIN PLATE ON THE SURFACE OF THE FORGING.

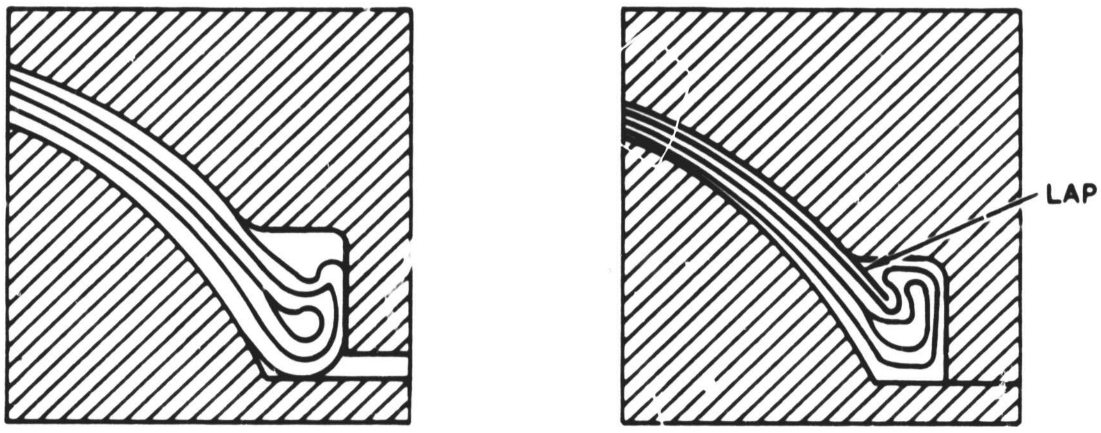
Turn to the next page.

From page 3-16

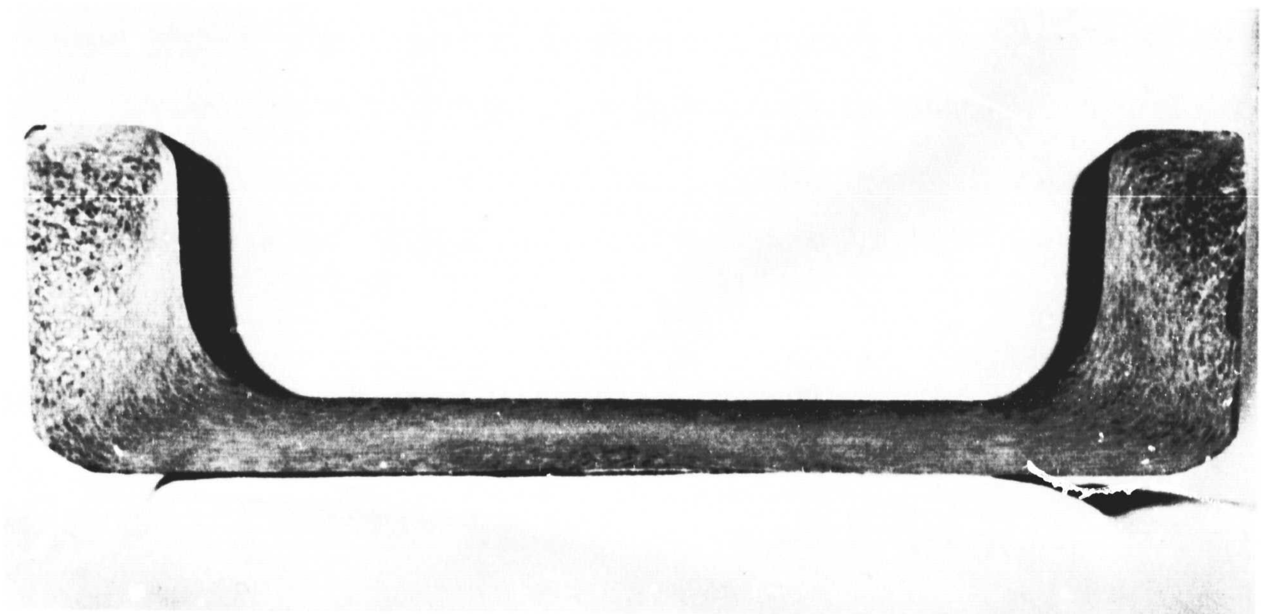
You are absolutely right. The definition of a forging lap is:

A FORGING LAP IS A DISCONTINUITY CAUSED BY FOLDING OF METAL IN A THIN PLATE ON THE SURFACE OF THE FORGING.

Forging laps can also be caused by poor die design. As the metal is pressed into the cavity in this die, the metal is forced up at the bottom of the die and tends to fold over on itself forming the forging lap shown on the right.



In a properly engineered die, there will be no forging lap.

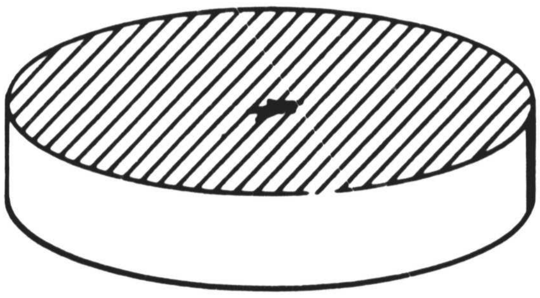


This picture shows the grain flow in a Titanium forging which does not have a forging lap in it.

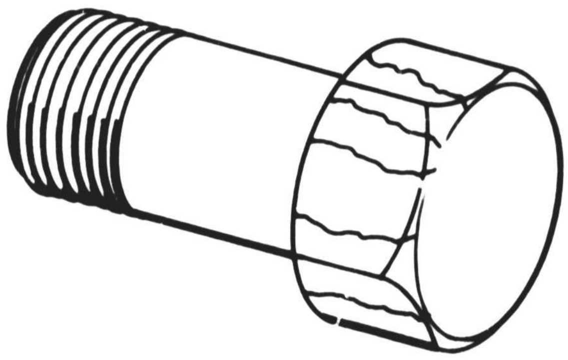
Remember, a forging lap is always open to the surface. Now let us discuss FORGING BURSTS which may be either open to the surface or sub-surface.

Turn to the next page.

A FORGING BURST IS A RUPTURE CAUSED BY FORGING AT IMPROPER TEMPERATURES. Forging a metal at too low a temperature may cause bursts. These bursts may be either internal or they may occur at the surface. Here is an example of each.



INTERNAL
BURST
(SUBSURFACE)



EXTERNAL
BURST OR CRACK
(OPEN TO THE SURFACE)

Improper temperatures caused these parts to break as the material was being shaped by forging. The metal was not hot enough and did not want to flow with the forging. It simply ruptured in the center when the metal was squeezed by the heavy forging press.

Which of the following conditions would likely cause a burst?

Overheating metal . . . . Page 3-21
Underheating metal. . . . . Page 3-22

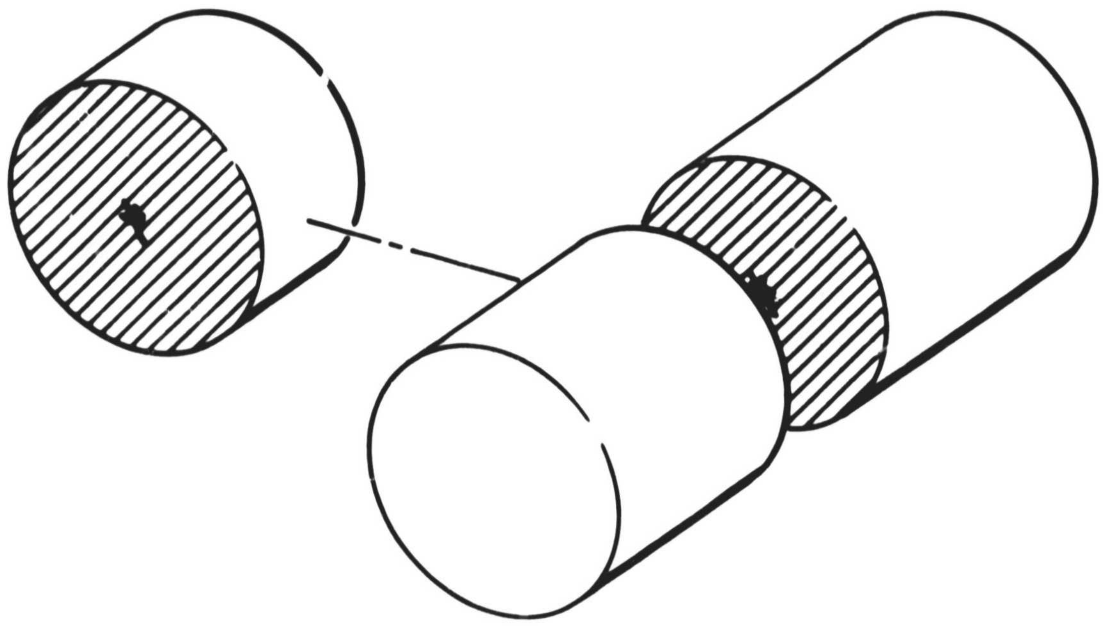
You selected overheating metal and that's not quite right. If the metal is overheated, it tends to be softer. If the metal is soft, it will more easily be worked into the shape of the dies.

If the metal is underheated, it is not as soft. The metal does not flow easily into the shape of the dies. As a result the metal cracks as it is worked.

Turn to page 3-22.

From page 3-20

You bet. Underheating of the metal would most likely cause a burst. Let's take a look at an internal burst.



We have sliced out of the center of the forging a piece of the metal so that you can see the burst in the center.

The center of this large piece of metal was not heat-soaked to the proper forging temperature before the forging operation began. Because the center was not hot enough, the metal did not want to flow with the forging. It simply ruptured or cracked in the center when the metal was squeezed by the heavy press.

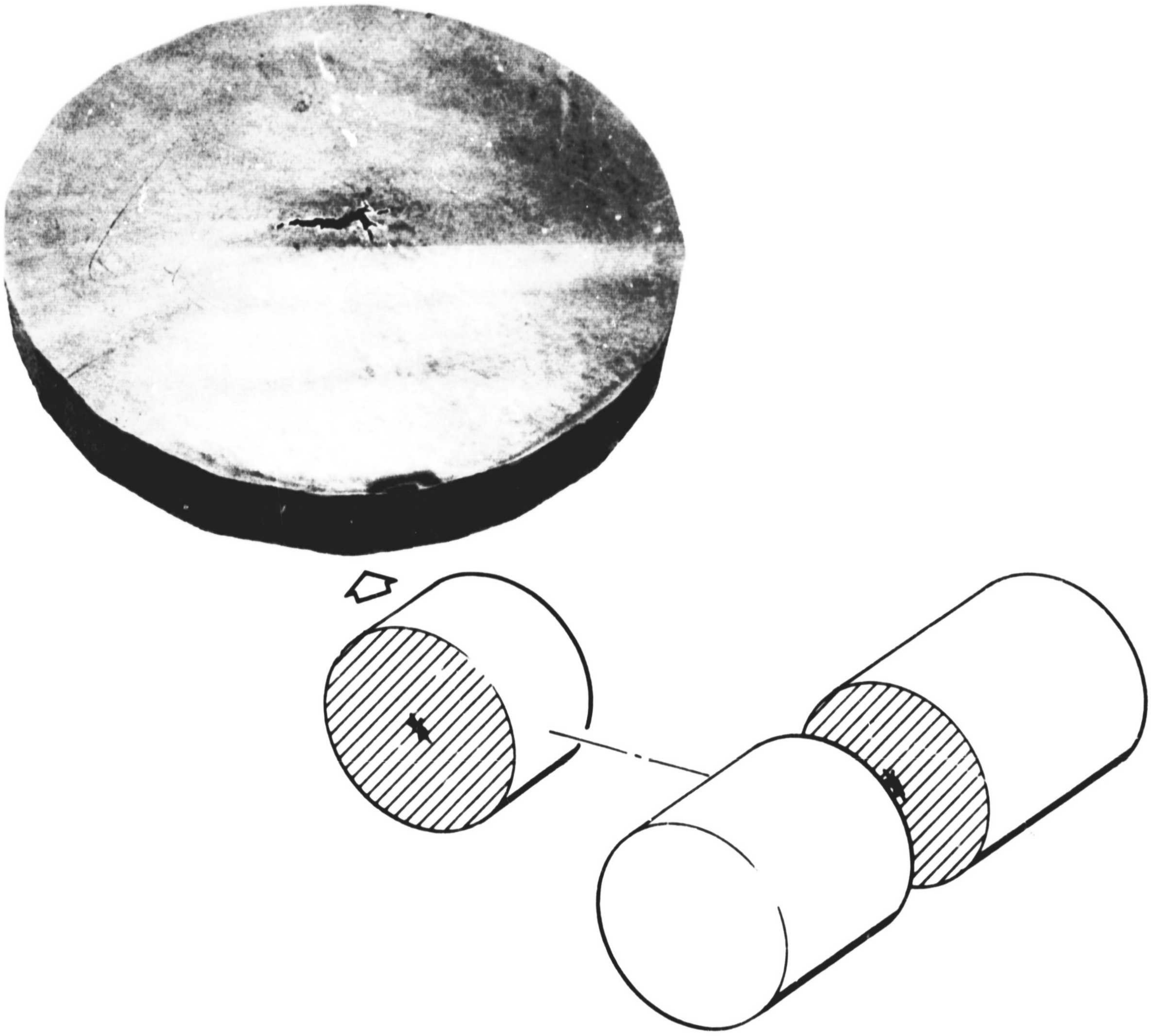
Would you expect to find the above internal forging burst open to the surface like a forging lap?

No . . . . Page 3-23

Yes . . . . Page 3-24

From page 3-22

No is the correct answer. An internal forging burst would not be open to the surface like a forging lap. To see an internal burst, you would have to machine away some of the metal. Here is an actual picture of that internal burst.



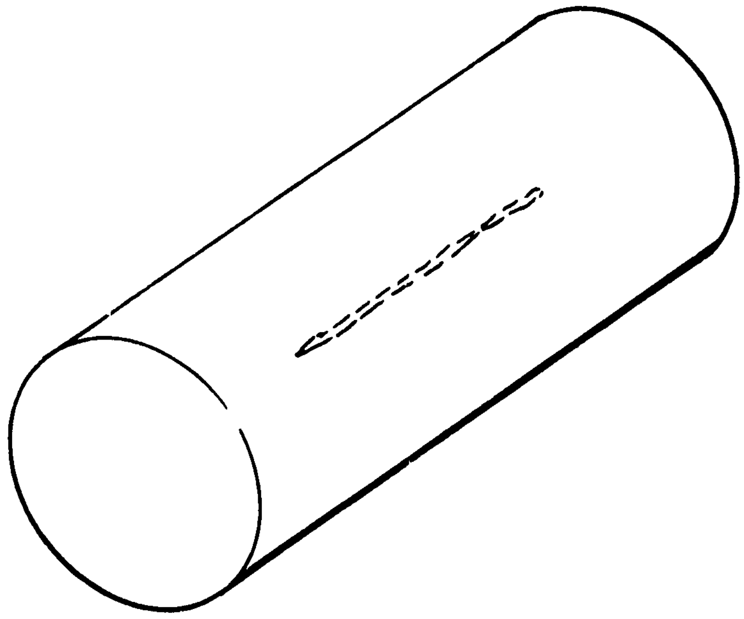
As you can see, the burst is very ragged and is close to the center of the metal. Would you expect to find all forging bursts or cracks only in the center of forgings?

No . . . . Page 3-25

Yes . . . . Page 3-26

From page 3-22

Yes was your selection. We haven't made the point clear. Let's take another look.



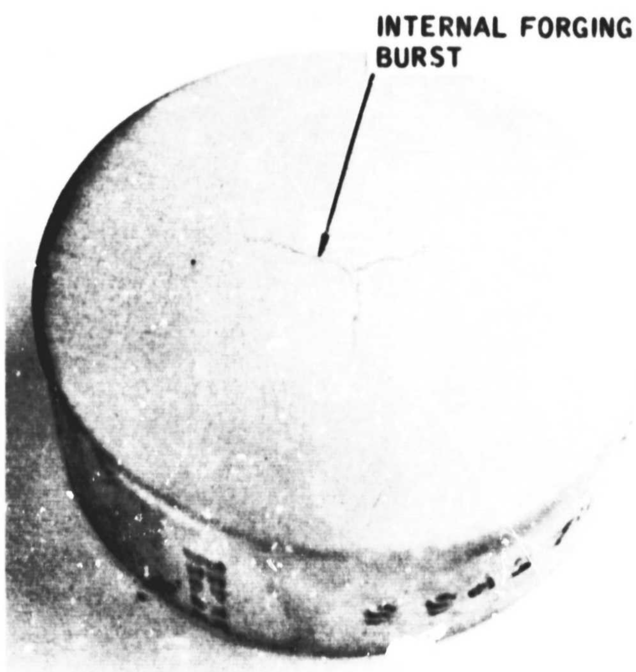
Here is the forging before we cut the slice out of the center. If we could see inside of the forging, the burst would look like the above.

We would not expect to find the internal burst open to the surface like a forging lap, because only the center was not heated sufficiently. The rest of the material was heated properly. Because the center was not hot enough, the metal did not want to flow with the forging. It simply ruptured or cracked in the center where it was not quite hot enough. So you wouldn't expect to find an internal burst like this one, open to the surface like a forging lap.

Turn to page 3-23.

From page 3-23

Of course. You wouldn't expect all forging bursts or cracks to appear only in the centers of forgings. There are both internal and external bursts. Here are two examples.



The photo on the left shows external bursts or cracks on the surface of the forging. On the right is an internal burst found in a forged bar of Titanium.

In summary, forging discontinuities can be caused when the metal being forged has not been heated throughout to the proper temperature. That portion which has reached the correct temperature will flow when forged. Any portion which has not been sufficiently heated, will not flow properly and may rupture. These discontinuities can be subsurface or open to the surface. These discontinuities are called forging bursts or forging cracks.

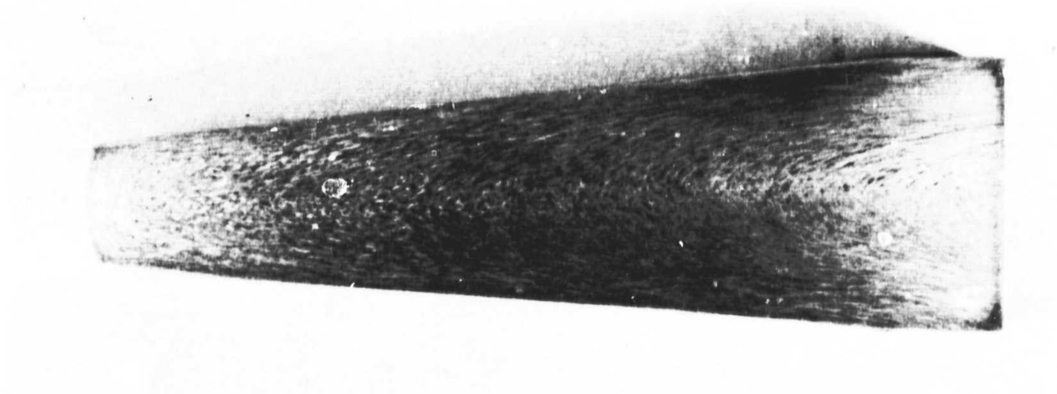
Turn to page 3-27.

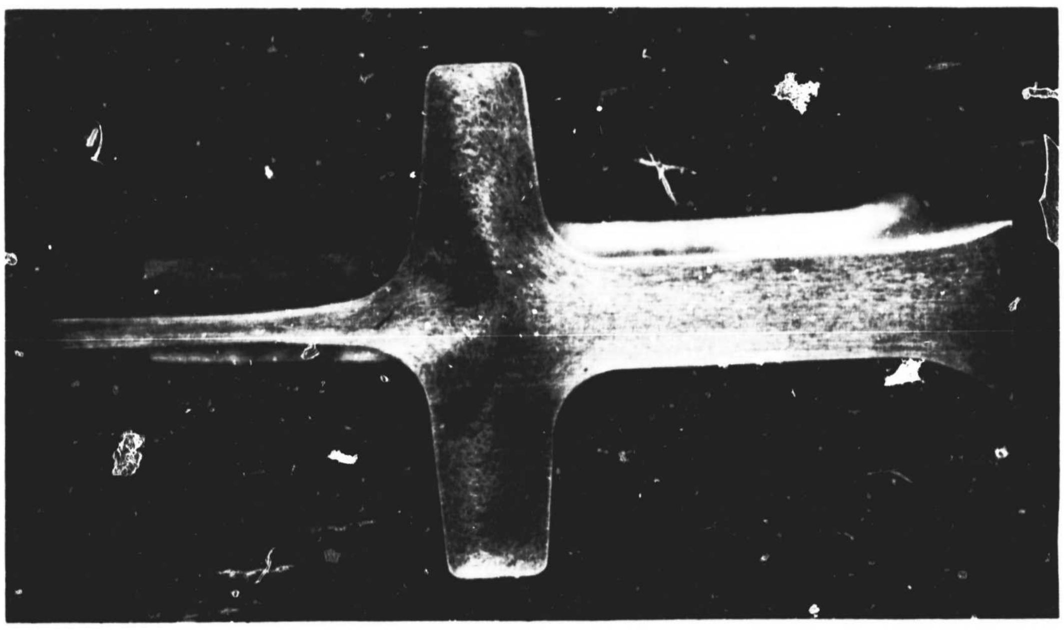
"Would you expect to find all forging bursts or cracks only in the centers of the forgings." You answered "Yes," which is incorrect. A forging burst or crack might occur in the center of the metal or it might have a surface opening.

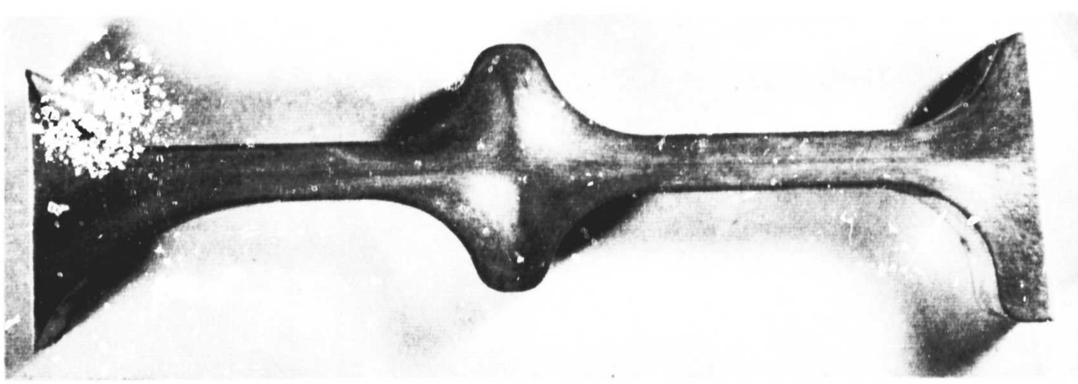
Remember the picture of the bolt with the cracks? Turn to page 3-23 for another look at forging bursts and cracks and read the summary.

From page 3-25

To review briefly, grain flow of a forging follows the shape of the forging contours. The importance of this is that the grain flow lines remain unbroken and the forging is unified into a continuous structure which is strong and tough. Here are some examples.



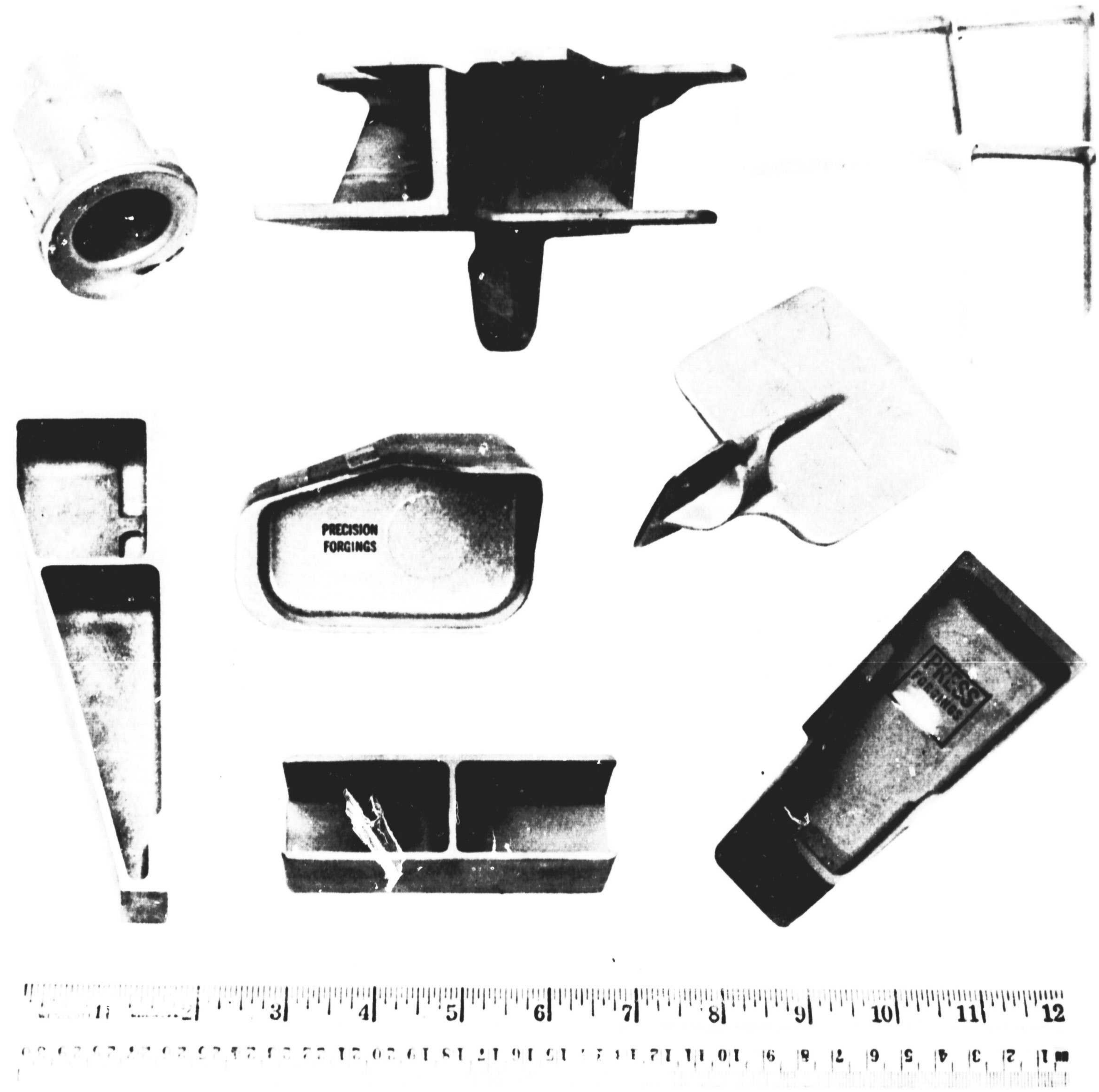




Turn to the next page.
[illegible]

From page 3-27

To meet the need of aerospace requirements, new forging techniques have been developed. High strength precision forgings of intricate design and small sizes are now available. Here are some examples.



Notice the size of the articles in relation to the twelve-inch scale.

Turn to the next page for a short review.

From page 3-28

1. Forgings are pounded or pressed into shape from preheated metal. As the metal is forged, the grain fol__________ the shape of the dies.

3. lap

4. A forging lap is always open to the __________ .

6. forging lap open

7. Another thing which could cause a forging lap is an abrupt change in grain _____ .

9. open
(sub)surface

10. As one might suspect, forgings bursts or cracks are ragged in shape. These ragged discontinuities would occur where the metal was (under) (over) _______ heated.

1. follows

2. If the dies happen to be mismatched, a sur______ discontinuity will be formed.

4. surface

5. Another possible cause of forging laps are abrupt changes in g__________ direction.

7. direction

8. Laps are not the only discontinuity found in forgings. Underheated metal might not allow the metal to flow properly and cause forging b____s or c____s.

10. under

11. If only the interior of a forged piece was underheated, the burst would be (open to the surface) (subsurface) __________.

2. surface

3. This surface discontinuity is caused by folding of the metal in a thin plate and is called a forging l_____ .

Return to page 3-29, frame 4.

5. grain

6. Mismated dies could be the cause of a __________ __________ . This would be __________ to the surface.

Return to page 3-29, frame 7.

8. bursts or cracks

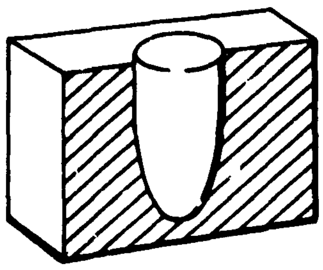
9. Forging bursts or cracks are simply a rupturing of underheated metal as it is forced into a new shape. These discontinuities can be _______ to the surface or they can be sub__________ .

Return to page 3-29, frame 10.

11. subsurface

12. Forgings and their discontinuities are a result of working hot but solid metal. For an account of parts made from molten metal, turn to page 4-1.

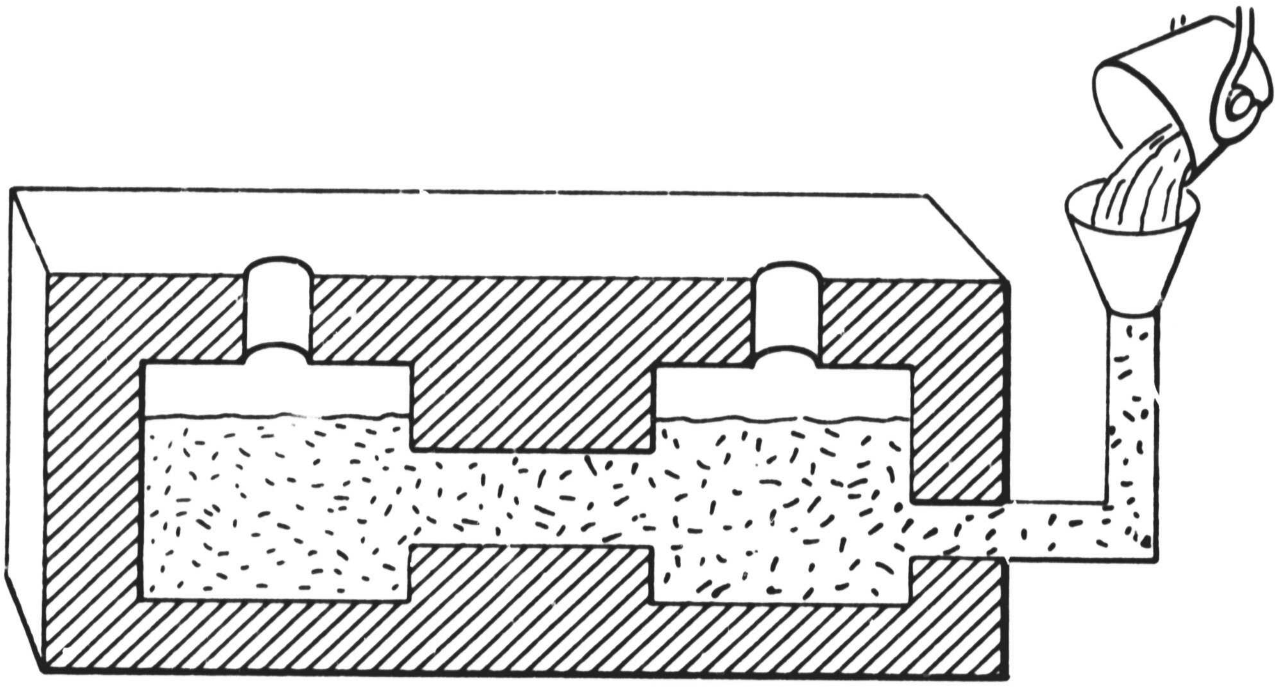
Castings are made by pouring liquid metal into a mold. These molds are formed close to the shape of the finished part. For example, many people cast their own bullets by melting lead and pouring it into a mold. When the metal solidifies it is removed from the mold.



Casting molds are usually made from sand, clay, and water. The clay and water form a thin film over each granule of sand, joining the granules to make the mold. As you might suppose, this mold can be easily broken and is permeable (absorbent). These are exactly the qualities which are wanted in a mold. You might also have guessed that castings have no regular grain structure. There is no rolling or forging to give direction to the grain.

Turn to the next page.

The illustration below shows a casting being poured. When it solidifies, it will have an irregular grain structure.



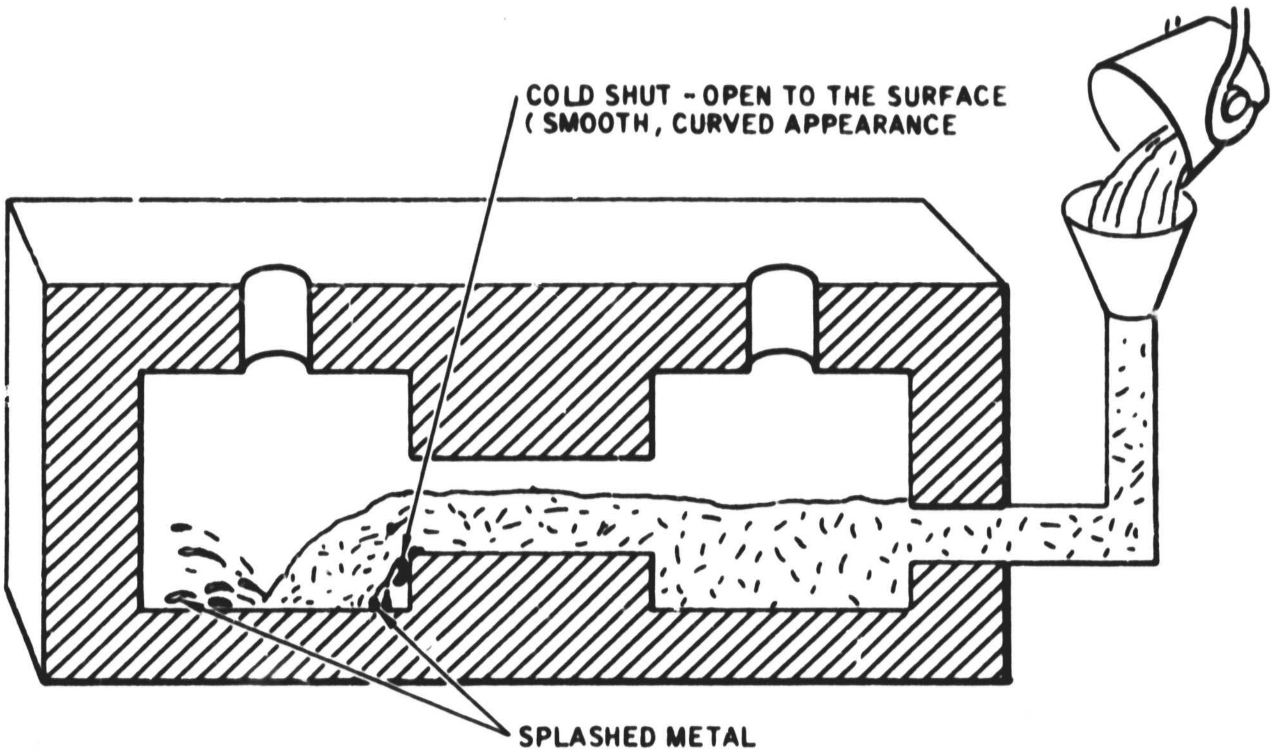
We are going to discuss several common types of discontinuities found in castings. The first discontinuity is a "cold shut."

<u>COLD SHUTS</u> are caused when molten metal is poured over solidified metal. When the metal is poured, it hits the mold too hard and spatters small drops of metal. When these drops of metal hit higher up on the mold, they stick and solidify. When the rising molten metal reaches and covers the solidified drops of metal, a crack-like discontinuity is formed.

When are cold shuts formed?

When molten metal is poured over solidified metal. . . . . Page 4-3
When molten metal is poured over molten metal . . . . Page 4-4

Good. A COLD SHUT is formed when molten metal is poured over solidified metal.



Cold shuts can also be formed by the lack of fusion between two intercepting surfaces of molten material of different temperatures.

Cold shuts are one type of discontinuity. The second type of discontinuity round in castings is HOT TEARS (shrink cracks). As the name implies, these cracks result from a tearing action within the metal. To better understand why this tearing action occurs, let's take another look at the ingot stage of steel-making.

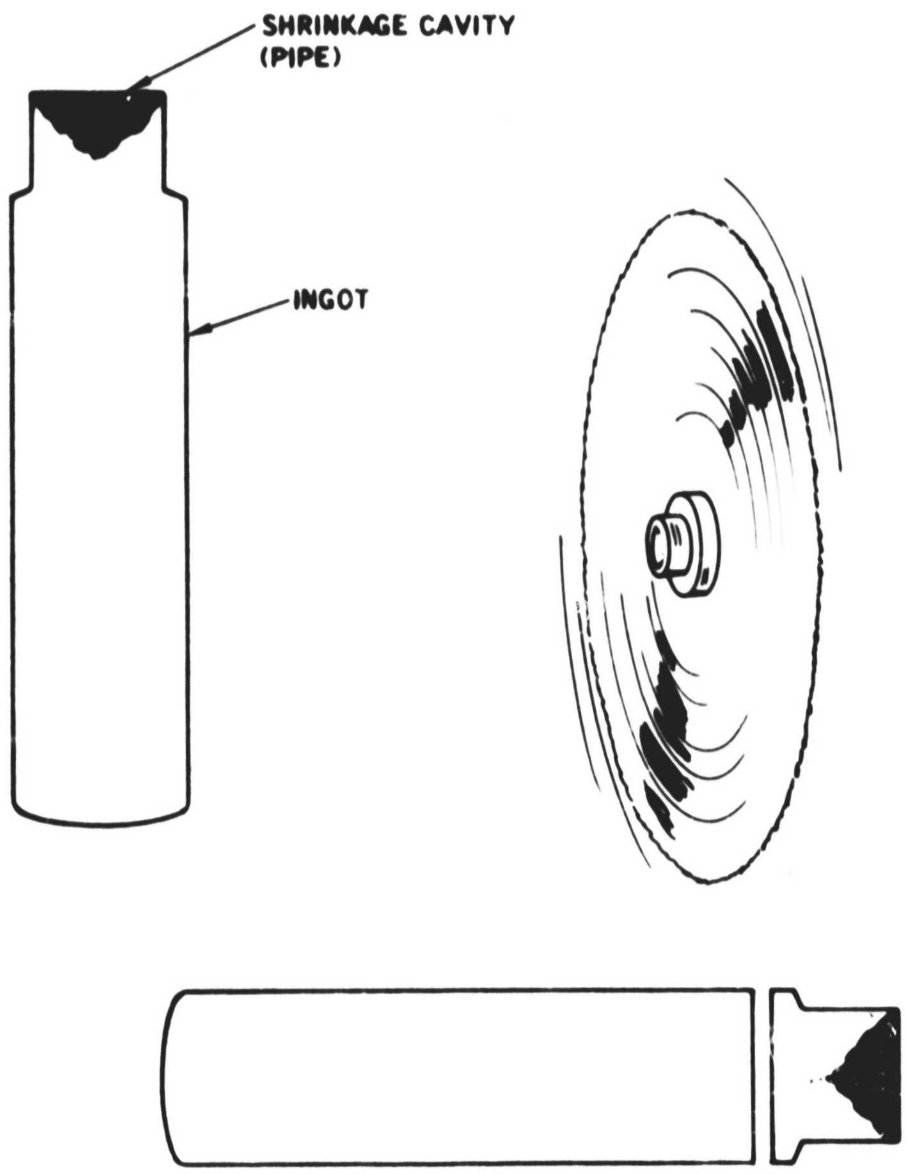
Turn to page 4-5.

From page 4-2

Molten metal poured over more molten metal would not form a cold shut. The clue here is in the word — COLD. A cold shut can only be formed by molten metal meeting with metal which has solidified or is relatively cold.

Turn to page 4-3 and continue.

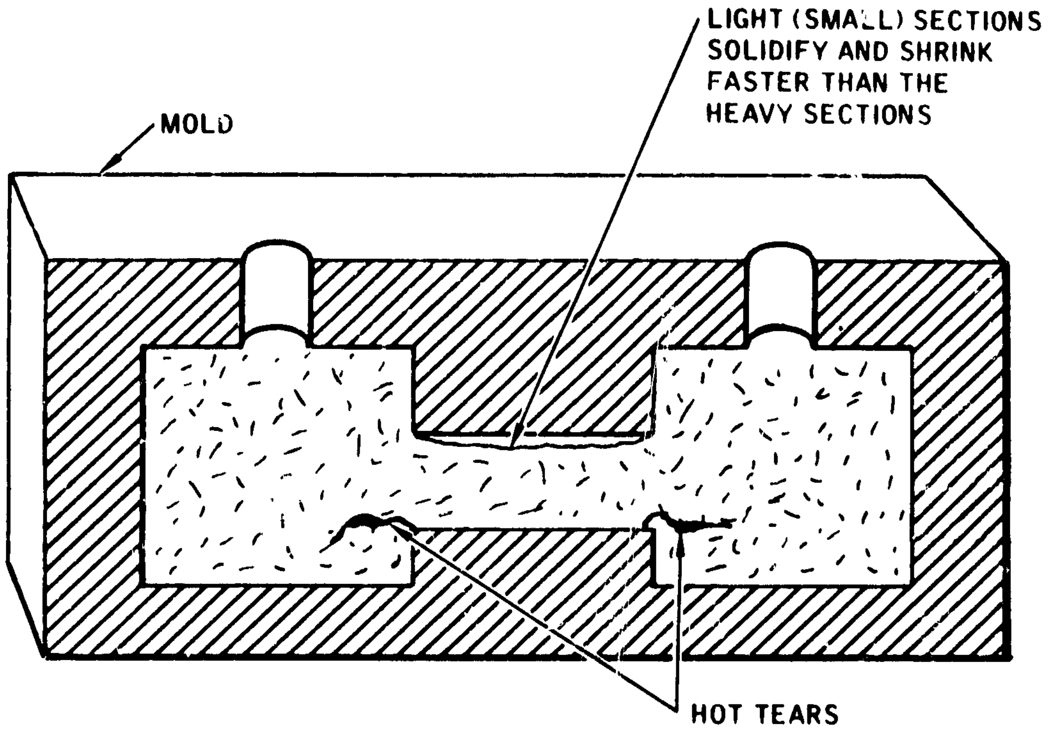
From page 4-3



The illustrations above should recall to mind that molten metal occupies more space than solid metal. In other words, metal shrinks as it solidifies. As the ingot solidifies, a shrinkage cavity forms in the top. The ingot is cropped, eliminating the cavity.

Turn to page 4-6.

The top of the open ingot was a natural place for shrinkage to occur. In a casting the shrinkage problem is not so simple. Consider the illustration below which shows hot tears caused by shrinkage.



In a casting having light and heavy sections, the light sections, being smaller, solidify faster; they shrink faster pulling the heavier sections, which are hotter and not shrinking as fast, toward them.

This unequal shrinking between the light and heavy sections:

Can cause shrinkage depression . . . . Page 4-7

Can cause hot tears . . . . Page 4-8

From page 4-6

Don't misplace the shrinkage depression--it belongs in the ingot! It is caused by the same action (metal shrinkage) which causes hot tears in a casting. But since a casting is more complicated in shape than an ingot, this force can cause more trouble than mere shrinkage depression.

Return to page 4-6.

From page 4-6

Well chosen! If a casting has light sections and heavy sections, the light sections solidify faster and shrink faster than the heavy sections. This unequal solidifying causes the faster-shrinking light sections to apply a pulling stress on the heavier sections. This creates stresses which can result in HOT TEARS at the junction of the light and heavy sections.

There is a way these tears can be prevented. In our discussion of castings, the composition of the mold was mentioned--sand, held together by clay and water. The mold is easily broken and is permeable (absorbent).

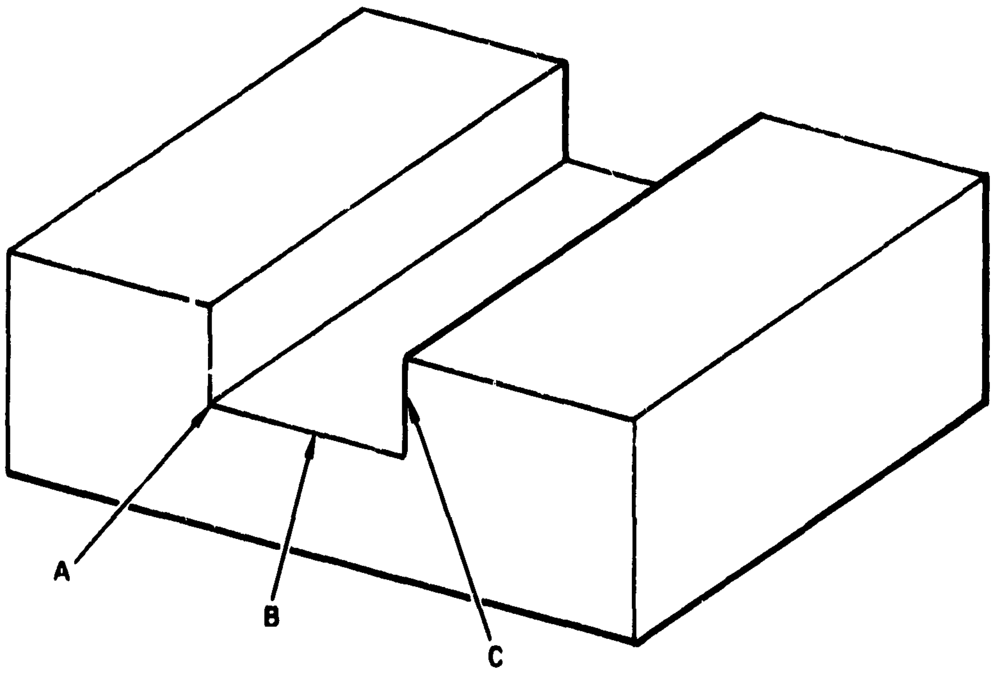
Hot tears can be prevented if, when stresses are built up by unequal shrinkage, the mold breaks before the metal tears. This breaking of the mold as the heavier sections are pulled against it, takes up the stress which might otherwise tear the metal.

Where are hot tears most likely to occur in a casting?

At the junction of light and heavy sections . . . . Page 4-9

Where the heavy sections contact the mold . . . . Page 4-10

Excellent. Hot tears are most likely to occur at junctions of light and heavy sections of a casting. Let's take a look at a casting which has been removed from its mold.



Where do you think a hot tear (shrink crack) would most likely occur in this casting?

Point A . . . . Page 4-11

Point B . . . . Page 4-12

Point C . . . . Page 4-13

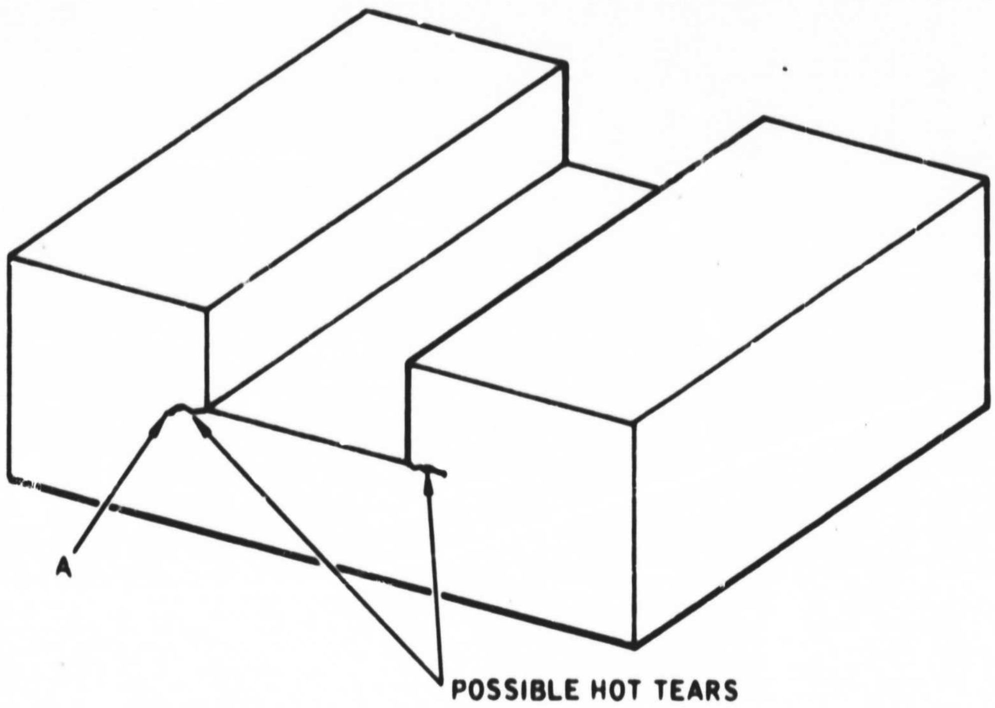
"Where the heavy sections contact the mold," is not the correct answer to the question:

"Where are hot tears most likely to occur in a casting?"

Remember that the name "hot tear" is descriptive. At a junction of light and heavy sections, unequal solidifying may cause the solidified light section to tear away from the heavier hot section. Hot tear.

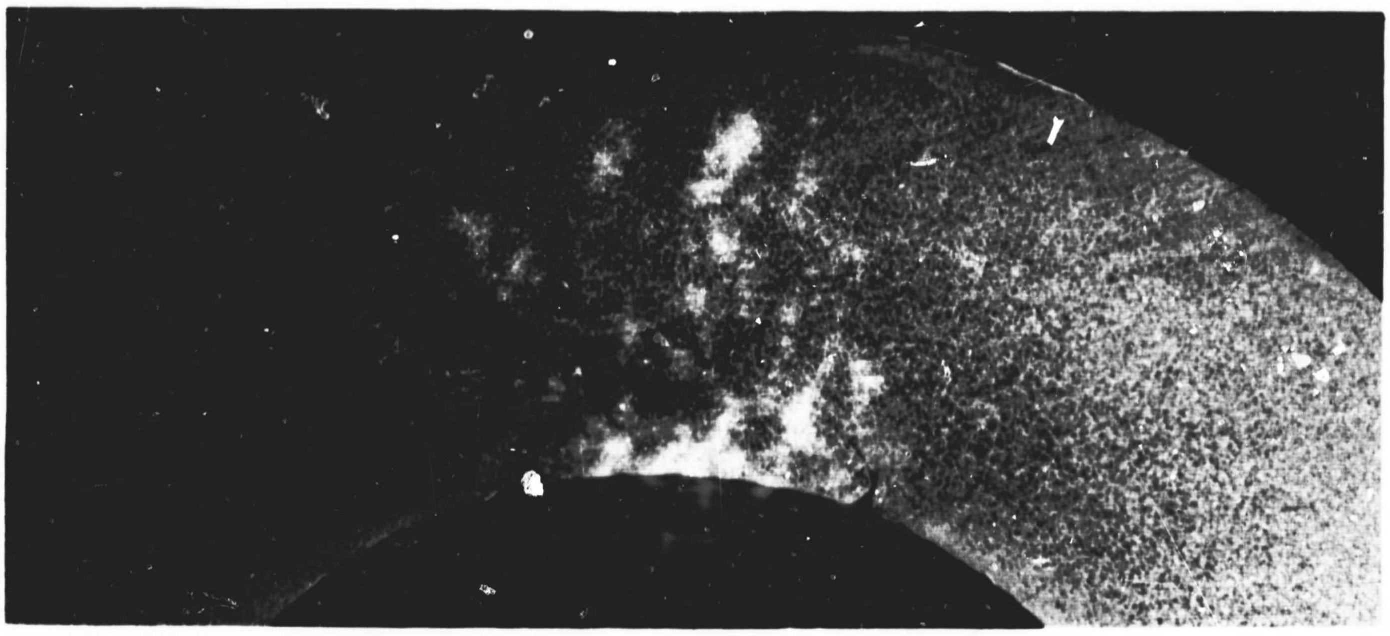
Turn to page 4-9 and continue.

Correct. You might possibly find a hot tear at Point A.



Points B and C were not located at the junction between heavy and light sections of the casting. But you might find another tear on the right side at the other junction of the light and heavy sections as shown above.

Hot tears do not look like COLD SHUTS. Hot tears have a ragged crack-like appearance.



What kind of a discontinuity is shown in this casting?

Hot tear . . . . Page 4-14
Cold shut . . . . Page 4-15

5000-0

Your answer --Point "B"--indicates a belief that a hot tear might be likely to occur here. This is the light section, true. But Point "B" is not a junction of the light and heavy sections. A hot tear would not be apt to occur here.

Take a second look at the picture on page 4-9 and select another answer.

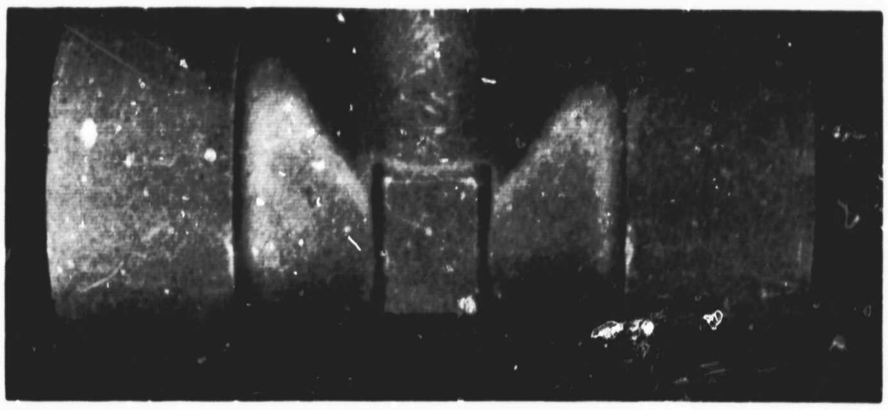
You chose Point "C" as the location at which a hot tear would most likely have occurred. Point "C" is a heavy section but it is not a junction between a light and a heavy section. It is at these junctions that a hot tear is most likely to occur.

Return to page 4-9 for another look at the picture and select the correct answer.

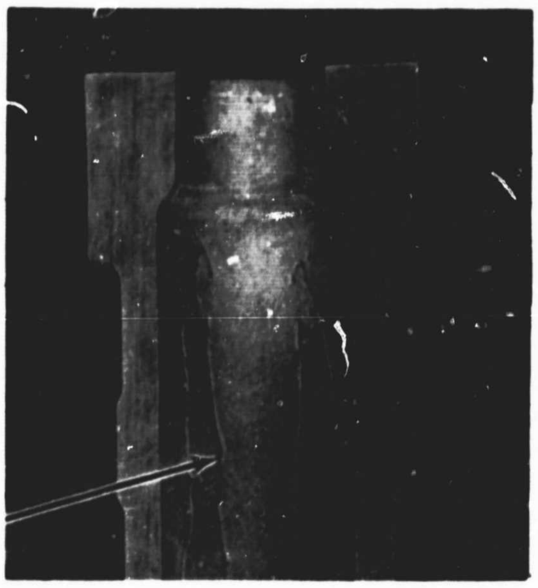
The discontinuity shown was not a hot tear. The discontinuity was pictured as a curving, not ragged, line. A hot tear was described as having a ragged appearance.

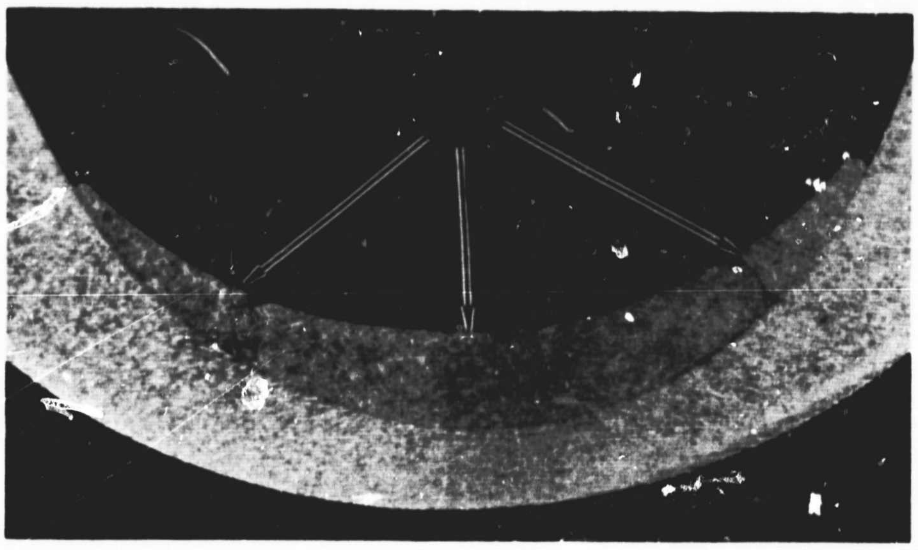
Turn to page 4-15 for another word about cold shuts.

That's a cold shut all right. A hot tear looks like a crack. Fine. Here is a cast aluminum joint.



Inside of the joint we have a discontinuity as shown by the following cross sectional views.



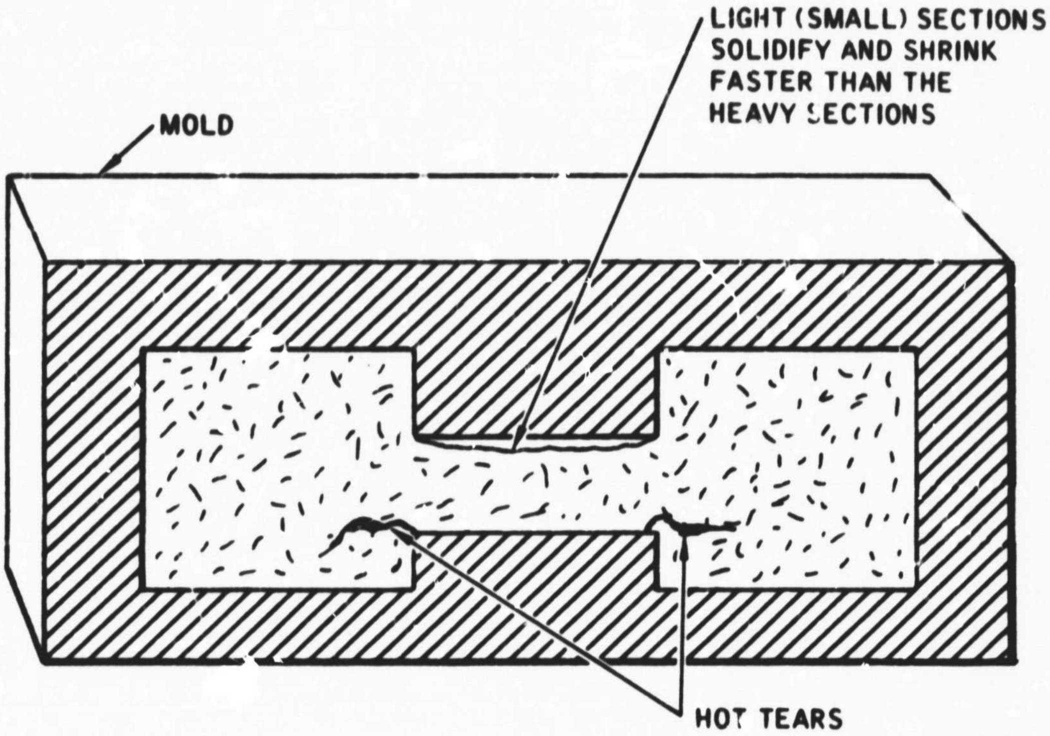


When the casting was poured, intersecting surfaces of the molten metal at different temperatures did not fuse on cooling. What is the name of this discontinuity?

Hot tear (shrink crack) . . . . Page 4-16
Cold shut . . . . Page 4-17

From page 4-15

No. The discontinuity shown is not a hot tear. A hot tear is caused by unequal shrinking of light and heavy sections of a casting as the metal cools. Here is the way hot tears look.

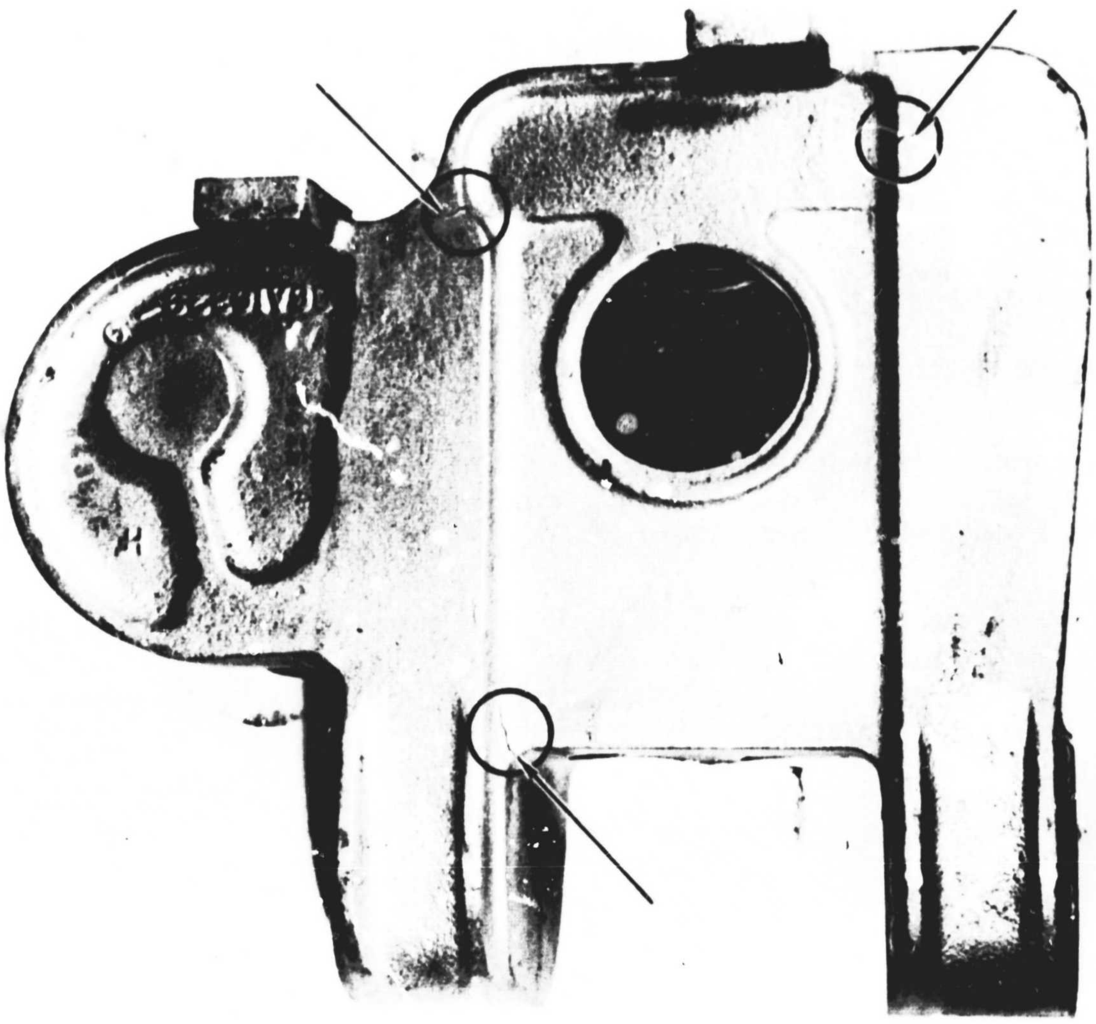


The discontinuity in question is one caused by intersecting surfaces of molten metal at different temperatures.

Return to page 4-15, review the photos, and select the other answer.

From page 4-15

Absolutely. That was a cold shut. When the casting was poured, some of the molten metal splashed onto the mold wall and solidified. When the rising molten metal reached the solid metal, it did not fuse and a smooth, curving COLD SHUT was formed.



Here is another casting with ragged looking discontinuities pointed out by the arrows. What is the name of this type of discontinuity.

Hot tear (shrink crack) . . . . Page 4-18
Cold shut . . . . Page 4-19

From page 4-17

Right. Those were hot tears--shrink cracks. Here is a close up of one of those shrink cracks.

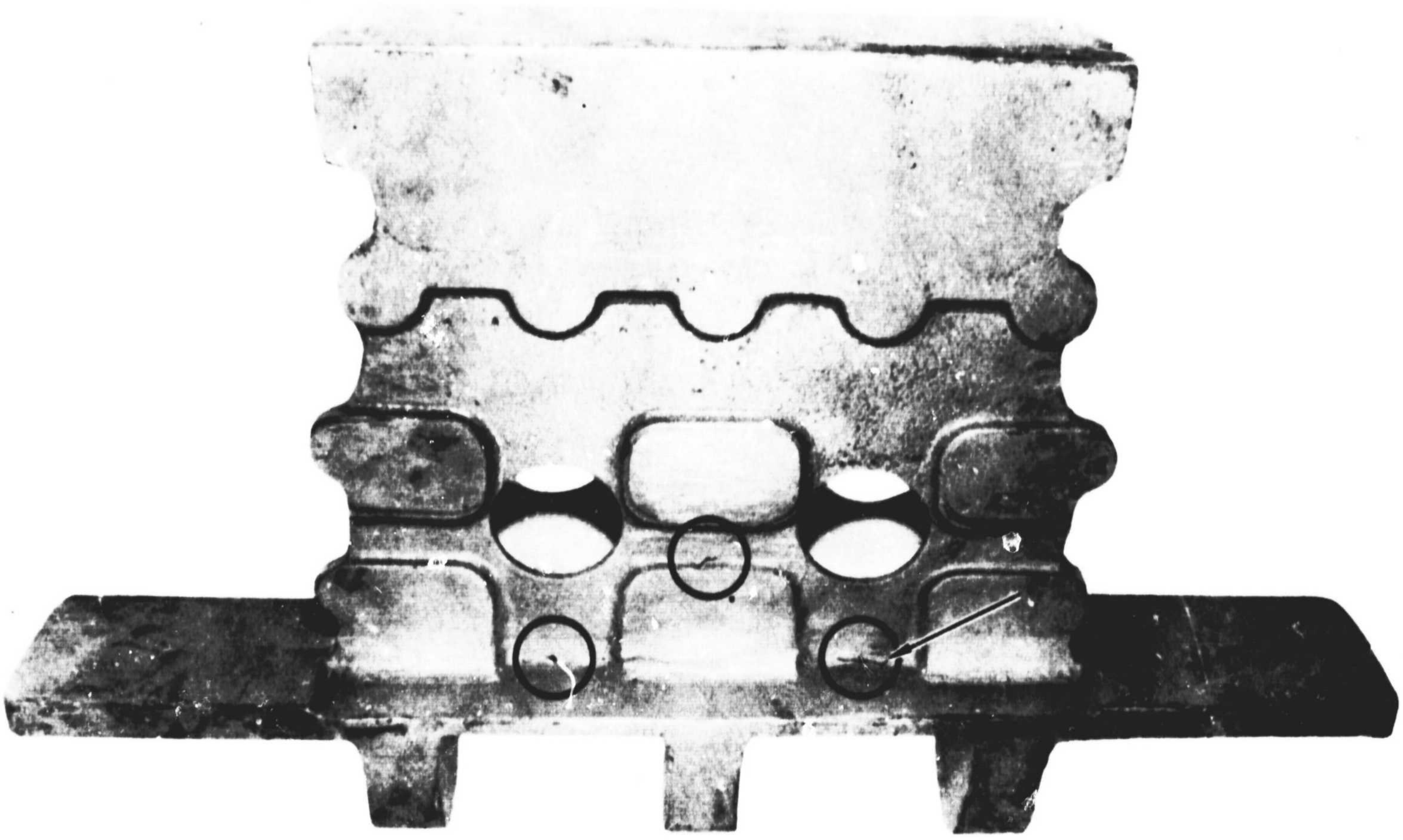
Notice the coarse texture of the surface of the casting and the ragged nature of the cracks.

Turn to page 4-20.

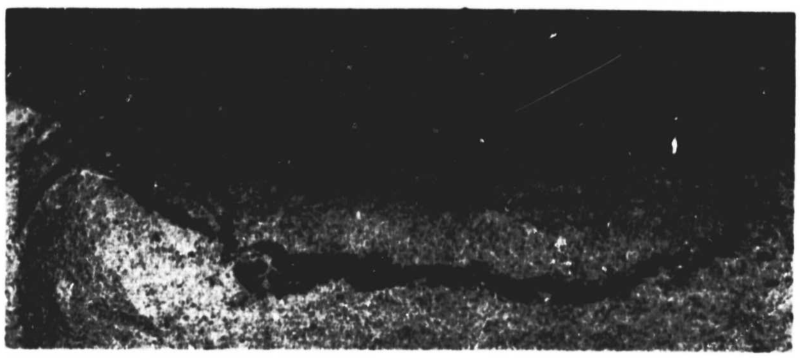
The discontinuity shown was not a cold shut. It did not show points where the metal did not fuse because of splashes on the mold wall. Instead it showed tears or cracks in the casting. These are hot tears (shrink cracks).

For a closer look at a hot tear, turn to page 4-18.

Here is another example of a hot tear or shrink crack. Here again, notice the coarse texture of the casting.



Below is a close-up of the shrink crack.



Another possible type of discontinuity, and our next topic of discussion, in castings is a SHRINKAGE CAVITY.

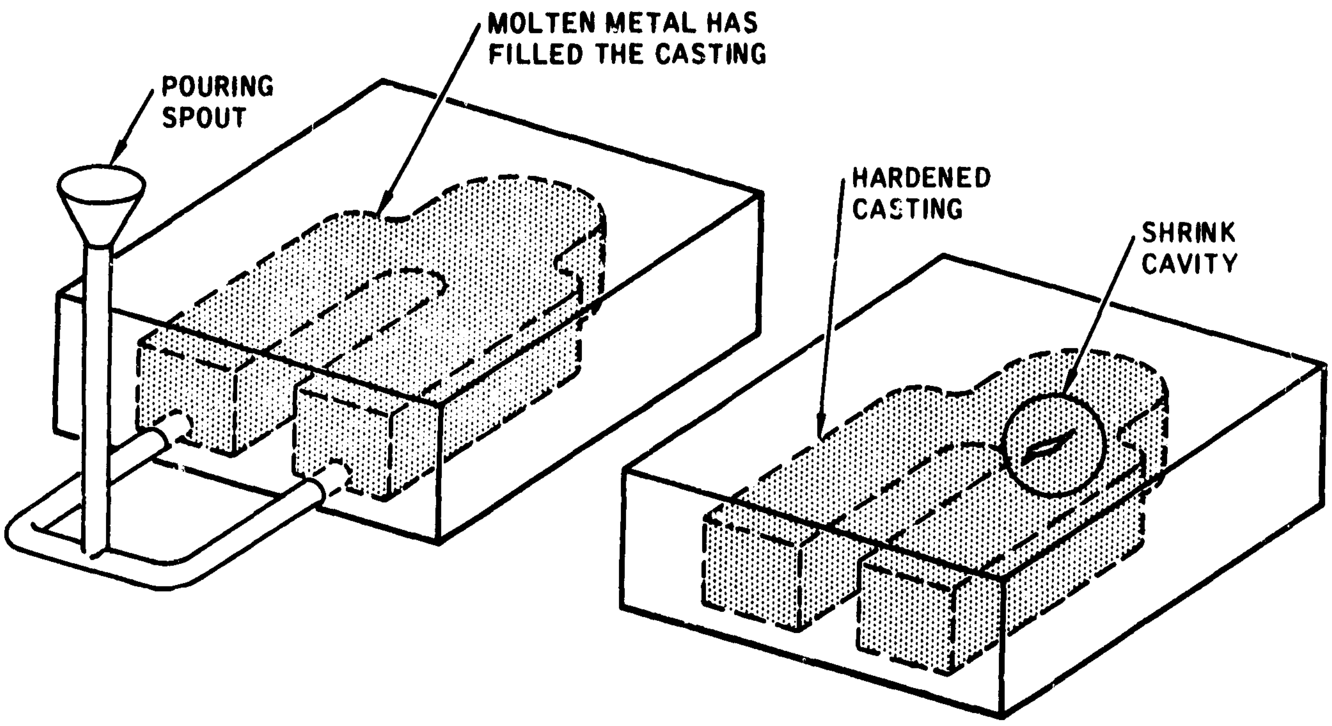
Turn to the next page.

From page 4-20

SHRINKAGE CAVITIES

Shrinkage cavities are caused by lack of enough molten metal to fill the space created by shrinkage just as pipe is formed in an ingot. This is the property which metal has of occupying more space when it is liquid than when it is solid.

Here are two molds. The dotted lines indicate the shape of the casting inside the mold. The left-hand drawing depicts the metal while it is still molten. The right-hand drawing shows the solidified casting with a shrinkage cavity.



Why is there a cavity in the solidified casting?

Only enough metal was poured to exactly fill the mold
while the metal was liquid . . . . Page 4-22

The metal burst in the center as it solidified . . . . Page 4-23

From page 4-21

Yes, there is a cavity because only enough metal was poured to exactly fill the mold when the metal was liquid. The metal solidified from the outer surface of the casting toward the heaviest part of the casting. As it was solidifying it was also shrinking and pulling the metal away from the liquid portion. Finally, as the last of the metal solidified and shrank away, a space remained because there was no metal left to compensate for the shrinkage.

Turn to page 4-24.

From page 4-21

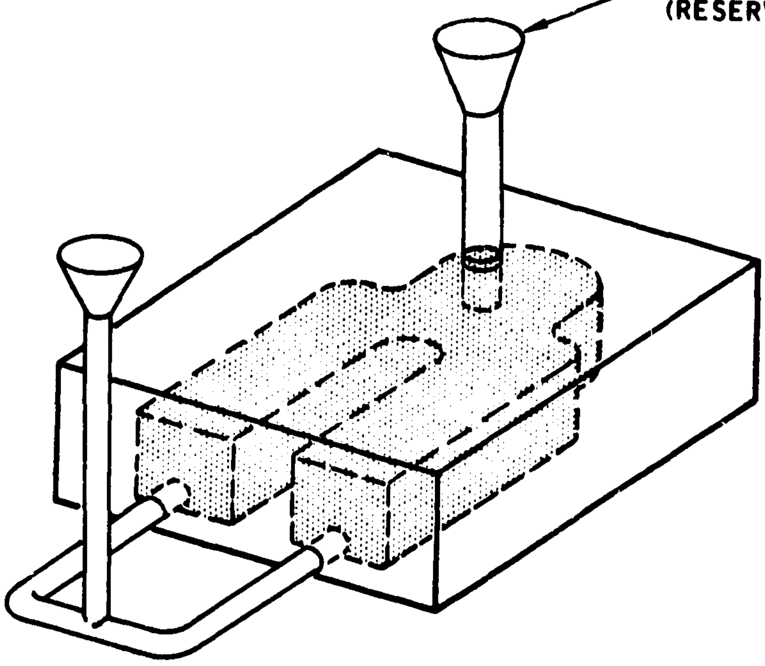
The cavity in the casting shown on page 4-21 was not caused by bursting of the metal as it solidified. A burst is a discontinuity which can be caused by forging processes.

The cavity in the casting was caused by shrinkage of the metal as it solidified. That is why it is called a shrinkage cavity.

Turn to page 4-22 and continue.

From page 4-22

There is a way in which shrinkage cavities can be eliminated or the possibility of shrinkage cavities can be greatly reduced. How? By adding a feeder head or reservoir as shown below.



Except for the addition of the feeder head, the casting above is exactly the same as the one which was shown on page 4-21.

The picture shows that more metal was poured into this casting than into the previous castings. After the casting was filled, the extra metal rose into the feeder head.

The additional metal which fills the feeder head will feed back into the casting to replace the metal which is shrinking. Under these conditions shrinkage will:

Eventually become a harmless, small cavity within the casting . . . . Page 4-25

Be absorbed by feeder head excess . . . . Page 4-26

From page 4-24

The purpose of the feeder head is not to make the cavity so small that it will be harmless, its purpose is to eliminate the cavity altogether--shrinkage eventually works its way into the feeder head!

Perhaps thinking of the process as a series of steps will help to establish it in your mind.

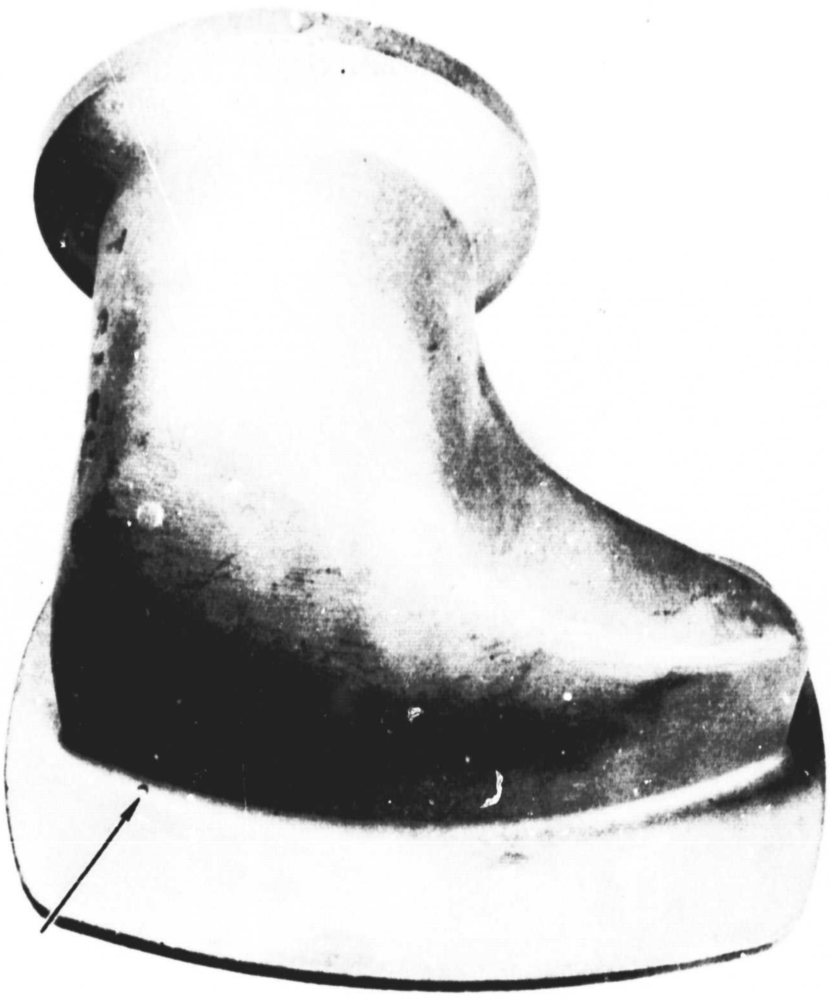
1. The metal is poured into the casting and fills the casting.
2. Pouring of the metal continues and the feeder head is filled.
3. A thin layer of the casting metal begins to cool and shrink.
4. Metal from the feeder head immediately replaces the space created by that shrinkage.
5. Another thin layer of the casting cools and shrinks.
6. Again metal from the header feeds in to replace the space created by shrinkage.

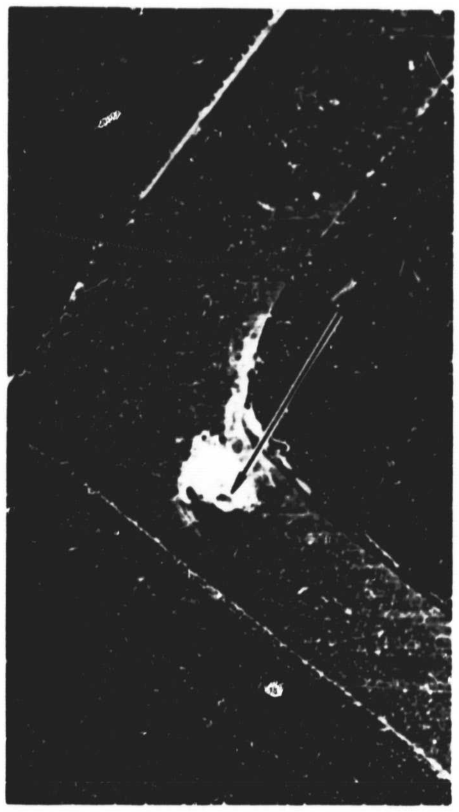
This series of steps is repeated again and again until finally the last metal to cool and shrink is the metal in the head. There is no metal left to fill in there but it doesn't matter. The head has fulfilled its purpose and will be removed.

Turn to page 4-26.

Correct. The shrinkage will be absorbed by the excess metal in the feeder head.

Since castings design can take any number of shapes, shrinkage cavities can appear at many points in a casting. Such is the case in this stainless steel casting.



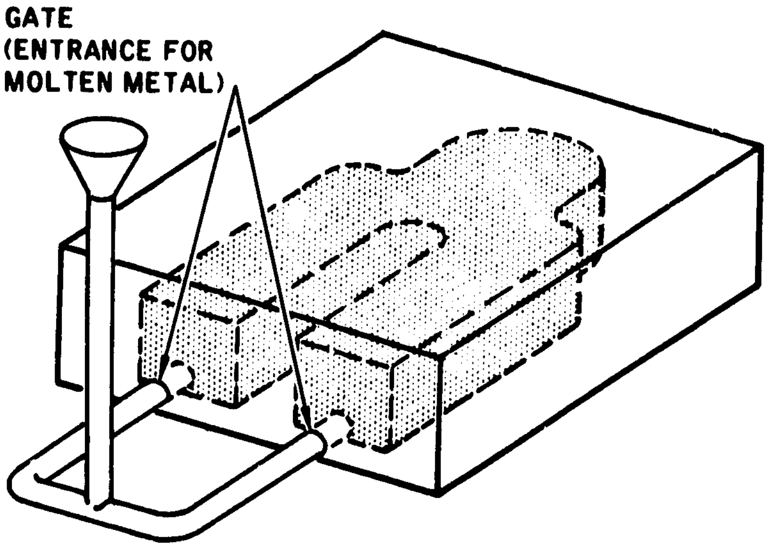


The shrinkage cavity in this casting, has a very small surface opening which is hardly visible. When the casting was cut through this section, the shrinkage cavity is clearly visible as shown by the picture on the right.

Turn to the next page.

53369

Shrinkage can also occur in the casting at the mold gate--the entrance to the mold through which the molten metal is poured.



Shrinkage can occur if metal at the gate solidifies or is blocked off while some of the metal beneath is still molten. Shrinkage which occurs at the gate appears as many small holes called MICROSHRINKAGE (small shrinkage). Since microshrinkage is caused by premature blocking of the gate, it is subsurface.

Microshrinkage can also occur deeper within the metal if the mold is improperly designed. For instance, metal might be poured into a heavy section of mold, flow through a light section, then into another heavy section of the mold. The entrance from the light into the heavy section might block off prematurely just as did the gate. If this happens, then microshrinkage would occur deeper within the metal.

If you were now asked to inspect a casting, where would you first look for possible discontinuities?

At junctions between light and heavy sections and at the gate . . . . Page 4-28

Along the edges of the casting. . . . . Page 4-29

From page 4-27

Of course. If you were given a casting, the most logical place to look for discontinuities (on the basis of information thus far) would be: At junctions between light and heavy sections and at the entrance to the gate.

One discontinuity which might occur at the junction between light and heavy sections is called a hot tear. It would be due to shrinkage. Another discontinuity which might occur at light and heavy junctions or at the gate is also due to shrinkage and is called:

Porosity . . . . Page 4-30

Microshrinkage . . . . Page 4-31

If given a casting for inspection, the most logical place to look for discontinuities on the basis of information provided thus far would not be along the edges of the casting.

We have discussed premature blocking of entrances--either at the gate, or at the junction of a light and heavy section of a casting. Logically then, you would look for discontinuities at these two locations.

Turn to page 4-28.

From page 4-28

The name of the discontinuity we want is MICROSHRINKAGE, not porosity. Although microshrinkage looks somewhat like porosity, the clue to the name of the underlined discontinuity is in the word shrinkage. Premature blocking of openings can cause [illegible] molten metal beneath the opening to shrink, creating an area of small holes. Micro means small so microshrinkage is the term for this discontinuity.

Turn to page 4-31.

From page 4-28

Correct. Microshrinkage is a discontinuity which might be found at junctions of light and heavy sections or which might be found at the gate. It is caused by premature blocking of an entrance either near the surface or deeper within the metal. Microshrinkage, therefore, is subsurface.

Turn to the next page for a discussion of still another possible discontinuity in castings--BLOW HOLES.

From page 4-31

BLOW HOLES

Blow holes are small holes in the surface of the casting caused by gas which is not within the molten metal--external gas. This external gas comes from the mold itself.

Remember the make-up of the mold? Its composition is sand, clay and water which is permeable or absorbent. When the molten metal contacts the mold, steam is formed by the water which is part of the mold. If the mold is permeable enough, the steam is forced through the mold to the outside.

If the mold is not permeable enough the steam cannot get through to the outside. Since it must go somewhere it is forced back into the casting blowing holes in the casting's surface--BLOW HOLES.

Where might you expect to find blow holes in a casting?

At the gate where the metal was poured .... Page 4-33

Somewhere on the surface of the casting .... Page 4-34

From page 4-32

You would expect to find blow holes somewhere on the surface of the casting, not at the gate where the metal was poured.

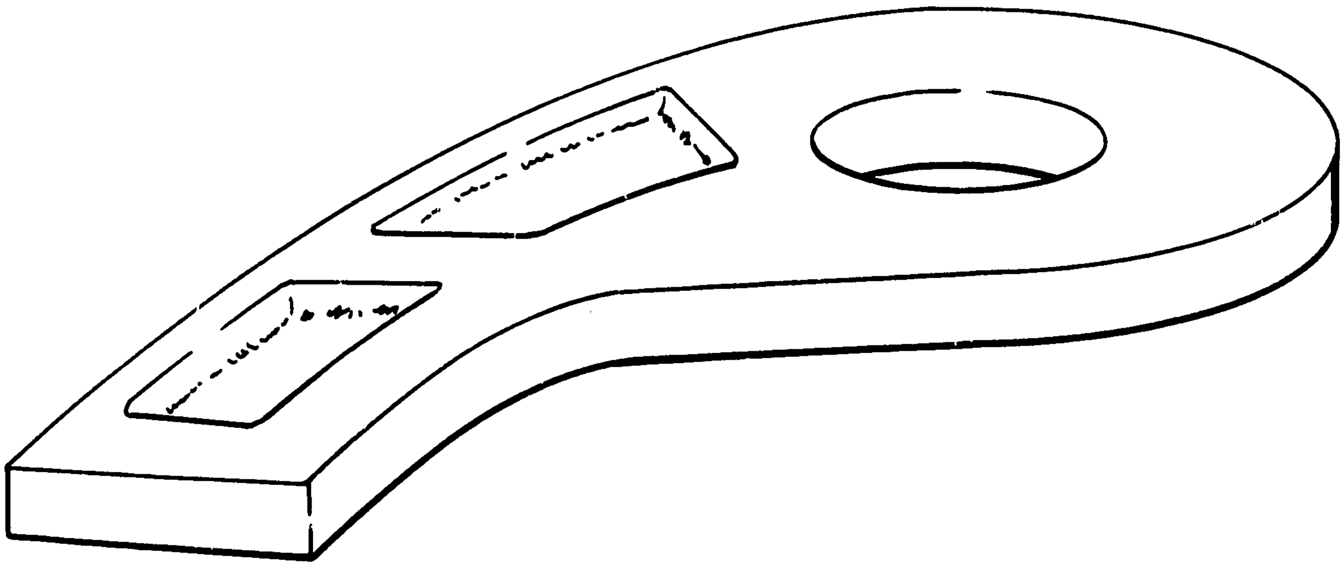
Blow holes are caused from steam within the mold. They would occur where the casting contacts the mold--the casting's surface.

Turn to page 4-34.

From page 4-32

Yes. Since blow holes are caused by steam within the mold, these discontinuities would occur somewhere on the surface of the casting--the point of contact with the mold.

The same principle applies in the case of cores, although the core is held together by oil rather than water. Since a core is surrounded by metal, the core must be vented to release the oil vapors. Inadequate venting can force the vapors into the surface of the casting where the casting contacts the mold core.



From the illustration of the casting above where do you think blow holes might occur?

On the surface of the casting but not in the wall of the hole . . . . Page 4-35

On the surface of the casting and on the wall of the hole . . . . Page 4-36

You answered that blow holes might be found on casting surfaces but would not be found on hole walls. That is incorrect because the hole walls were formed by part of the mold--the core. So, blow holes might be found on casting surfaces as well as hole walls which are actually part of a casting's surface.

Turn to page 4-36.

Right. Blow holes can occur on the surface of the casting as well as on the wall of the hole. Both of these surfaces touch the mold.

Still another discontinuity found in castings is the now-familiar POROSITY. Porosity in castings is caused by entrapped gas--the same way it is caused in the ingot. Porosity can be either at the surface or subsurface depending on the design of the mold or configuration of the article. Here is an example of porosity in the surface of a casting.

We have discussed six types of discontinuities which might be found in castings. The names of the discontinuities provide a clue to their cause.

COLD SHUTS--Hot metal over solidified metal or intersecting surfaces at different temperatures.

HOT TEARS (SHRINKAGE CRACKS)--Tears in metal from unequal cooling.

SHRINKAGE CAVITIES--Subsurface cavities caused by shrinkage.

MICROSHRINKAGE--Many small subsurface cracks or cavities.

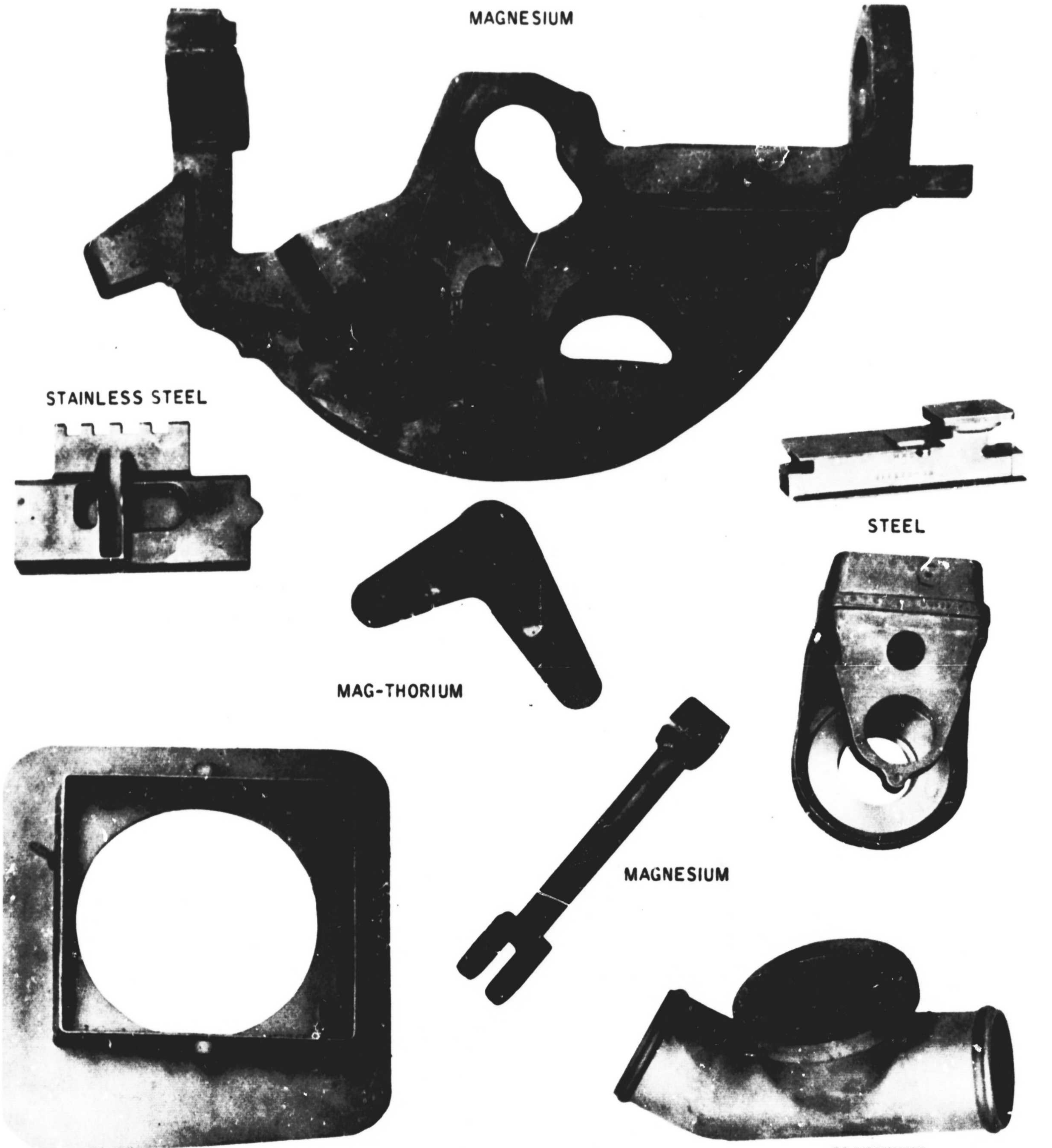
BLOW HOLES--Holes blown into a castings surface.

POROSITY--Entrapped gas.

Turn to the next page.

From page 4-36

Before going on to other metal forming processes, here are some examples of space age type precision castings. Notice the intricate design and small size of these castings in relation to the scale at the bottom.



Turn to the next page.

From page 4-37

These castings are all steel with variations in alloys.

Turn to the next page for a review of casting discontinuities.

From page 4-38

1. Castings are made by pouring liquid metal into a mold. There are several kinds of breaks or dis________________ which can occur in castings.

5. tearing

6. These ________ ______ caused by the tearing action of shrinking metal, are most likely to occur at junctions of l_______ and h_______ sections.

10. cavity

11. The addition of a feeder head to feed metal into the casting as it solidifies will prevent s___________ c___________.

15. light (and) heavy

16. The junction between light and heavy sections could act as an entrance, prematurely block off, and cause _________ __________________.

1. discontinuities

2. When the casting is poured, drops of metal can splash up on the inside walls of the mold. These drops stick and solidify. When the rising metal covers these solidified drops, crack-like discontinuities are formed. These are called co_______ sh_______ .

6. hot tears
light (and) heavy

7. Cold shuts have a smooth, curved appearance. Hot tears are r_____ed in appearance.

11. shrinkage cavities

12. Shrinkage can cause another discontinuity which would also be located beneath the metal's surface. This shrinkage is located at the g________ where the metal enters the casting.

16. microshrinkage

17. A mold is made up mostly of sand, clay, and water. Where the molten metal contacts the mold steam is created. If the mold is made correctly the steam is forced to the out________ .

2. cold shuts

3. Cold shuts within a casting--the result of molten metal covering solidified metal or two intersecting molten surfaces at different temperatures--have a smooth, slightly cur__________ appearance.

7. ragged

8. Another kind of discontinuity which can develop in castings is a result of the property which metal has of sh__________ as it solidifies.

12 gate

13. Unlike a shrinkage cavity, shrinkage at the gate is not a single cavity. Shrinkage which occurs at the gate takes the shape of many small holes called m__________ shrinkage.

17. side

18. If the mold does not allow this steam to escape, it will be forced or blown back into the sur________ of the casting causing b_____ holes.

3. curved

4. A smooth, curved discontinuity in a casting might indicate a________ shut. Another discontinuity which might occur in castings has a ragged crack-like appearance and results from metal shrinkage. It is called a hot t________.

8. shrinking

9. This discontinuity is caused by shrinkage, and is called a __________ cavity.

13. micro

14. Micro means small so m______ s__________ is actually small shrinkage. This discontinuity is caused by premature b__________ing of an entrance, allowing the still-molten metal beneath to shrink.

18. surface
blow

19. These discontinuities caused by steam can occur anywhere the mold contacts the casting--including the surface of a core. B______ h________ then, are surface discontinuities.

4. cold

(hot) tear

5. When there are light and heavy sections in a casting, the light sections shrink faster and tend to pull away from the heavier sections. If the mold does not break soon enough, there is a t__________ing action in the metal.

Return to page 4-39, frame 6.

9. shrinkage (or shrink)

10. Shrinkage cavities are caused when too little metal is poured to make up for the shrinkage which occurs as the metal solidifies. The metal shrinks and a subsurface c__________ is formed.

Return to page 4-39, frame 11.

14. microshrinkage

blocking

15. The gate where the metal is poured is not the only place where premature blocking or shutting off of an entrance might occur. The other place would be at a junction between l________ and h__________ sections.

Return to page 4-39, frame 16.

19. Blow holes

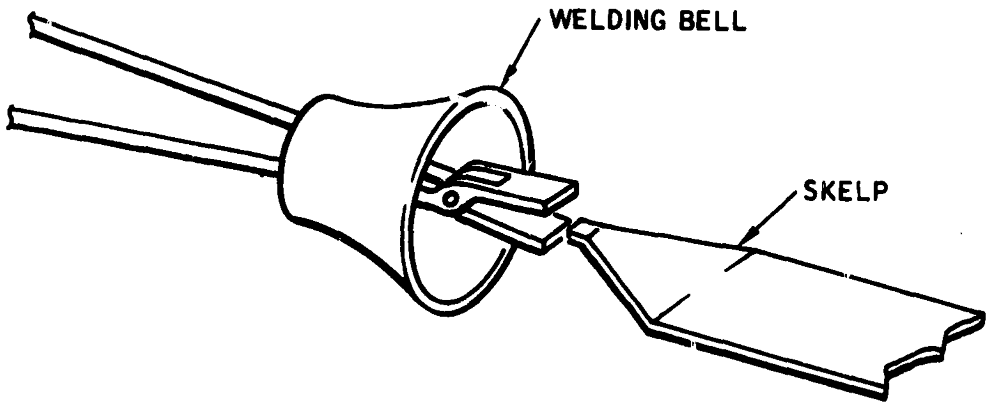
20. The last discontinuity for consideration in castings is POROSITY. Porosity is caused by entrapped gas and is round, or nearly round in shape.

Turn to the next page.

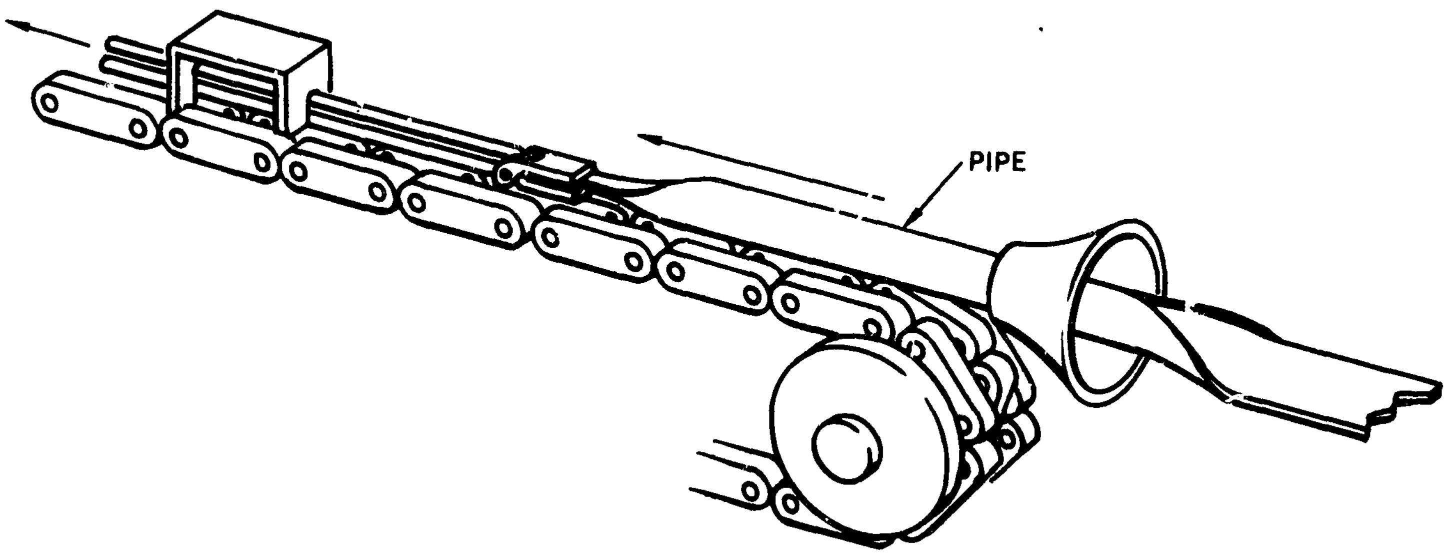
Pipes and tubes fall into two categories; welded and seamless. Welded pipe has a seam along its length but seamless pipe has no seam or weld.

WELDED PIPE

Welded pipe is made from a narrow flat piece of steel called skelp. The skelp is heated to a welding temperature and then grasped by a pair of tongs and pulled through a die called a welding bell.

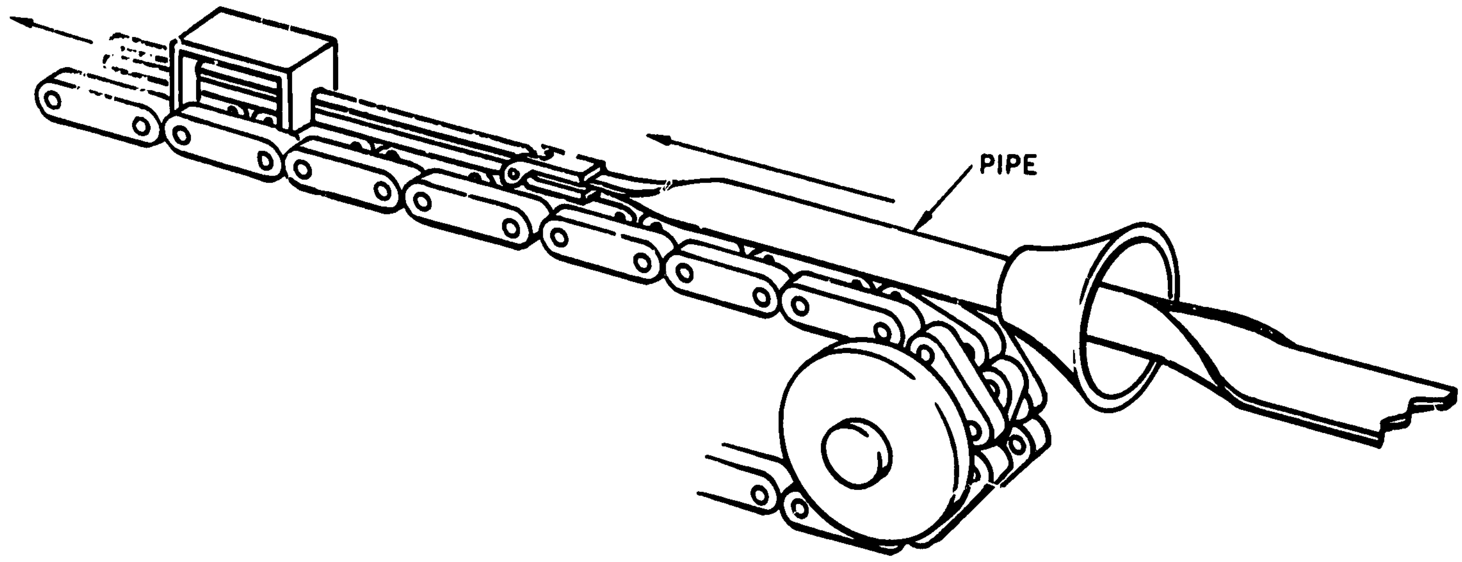


The tongs are then attached to a moving chain which pulls the skelp through the welding bell. Because the skelp is heated to welding temperature, it welds or fuses when the two edges come together in the shape of a round pipe.



Turn to the next page.

Actually the material is fused where the two edges come together if the proper temperature is maintained.



If the proper temperature is not maintained, there may be intermittent lack of fusion or intermittent cracks. These cracks may appear either on the inside or outside of the pipe. Which of the following types of discontinuities do you think fits the description of the cracks.

Stringer . . . . Page 5-3
Seam . . . . Page 5-4
Lamination . . . . Page 5-5

From page 5-2

Nope. The cracks caused by lack of fusion in the welding of pipe are not called "stringers." A stringer is a discontinuity we learned about when we discussed the working of a billet. It is defined as:

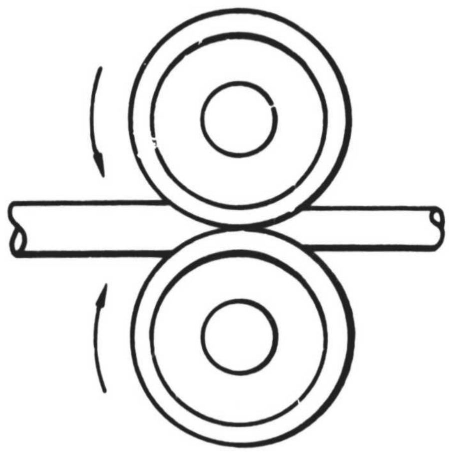
> A non-metallic inclusion which is elongated as the billet is rolled into bar stock.

As the skelp is pulled through a welding bell to form pipe, the edges should fuse (or weld) when they come together. Intermittent cracks may occur from lack of fusion if the proper temperature is not maintained in the metal. This discontinuity would be called a...

...seam . . . . Page 5-4
...lamination . . . . Page 5-5

Right. Lack of fusion in the welded pipe could cause a seam. The seam might appear either on the inside or outside of the pipe. Any nick or crack in the skelp or defect in the welding bell die, will result in a lap or crack-like discontinuity in the finished pipe.

After the pipe is formed in the welding bell die, it is put through sizing rolls. These rolls reduce the pipe to its proper size and make it perfectly round.



Here are two typical sections of pipe made by the welding process.

Since the weld runs the length of the pipe, any discontinuity caused by faulty welding would be called:

A hot tear. . . . . Page 5-6

A stringer . . . . Page 5-7

A seam . . . . Page 5-8

That's wrong. The cracks caused by lack of fusion in the welding of pipe are not called "laminations." A lamination is a discontinuity we learned about when we discussed the rolling of a slab to form sheet or plate stock. It is defined as:

> A non-metallic inclusion which is flattened as a slab is rolled into plate stock.

As the skelp is pulled through a welding bell to form pipe, the edges should fuse (or weld) when they come together. Intermittent cracks may occur from lack of fusion at the welding edges if the proper temperature is not maintained in the metal. This discontinuity would be called a...

...stringer . . . . Page 5-3
...seam . . . . Page 5-4

From page 5-4

No. It looks as if you have some definitions mixed up. A discontinuity caused by faulty welding in a pipe would not be called a hot tear. A hot tear is a type of discontinuity that occurs in a casting. It is likely to occur at a junction of light and heavy sections of a casting.

A discontinuity in the weld of a welded pipe is something quite different.

Return to page 5-4 and select another choice.

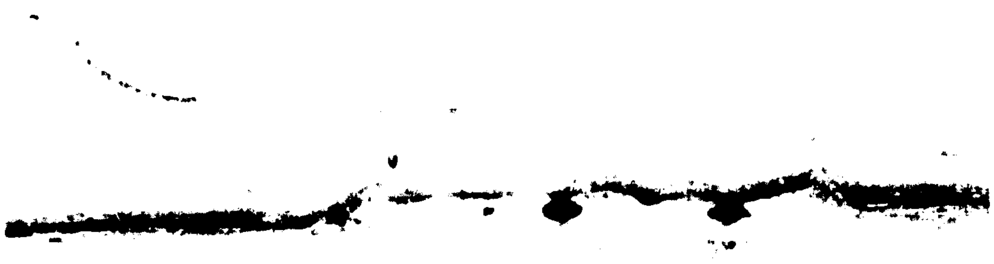
Wrong choice. It looks as if you have some definitions mixed up. A welding discontinuity in a piece of welded pipe is not a stringer. A stringer is a non-metallic inclusion in bar stock.

A discontinuity in the weld of a pipe is something quite different.

Return to page 5-4 and select another answer.

From page 5-4

That's right. Faulty welding in a pipe would be called a seam. Here is an example of a seam on the inside surface of tubing or pipe. The example has been magnified many times.

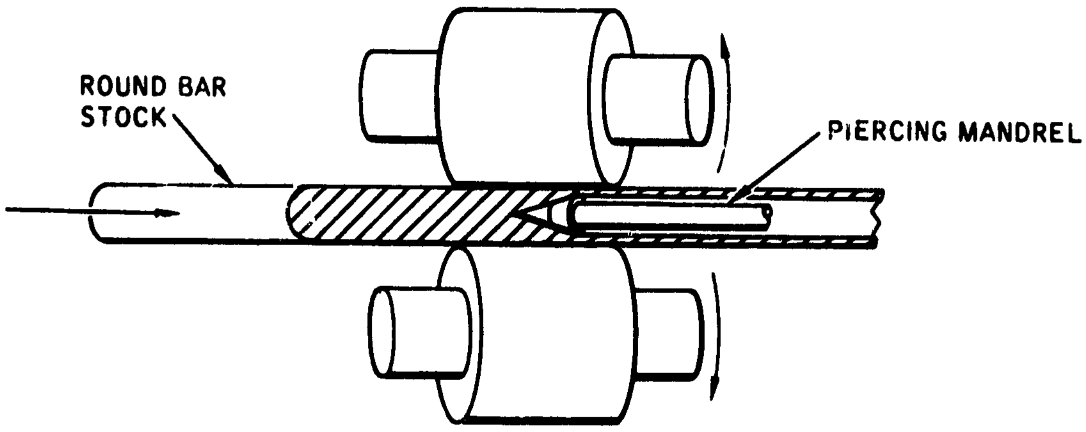


Since welded pipe or tubing is made from sheet or plate material, discontinuities found in them would also be found in the pipe made from these materials. Laminations caused by flattened out non-metallic inclusions or porosity would be found in the pipe.

Turn to the next page.

SEAMLESS PIPES AND TUBES

Seamless pipes and tubes are made from bar stock or billets. In this process, the bar stock is heated to rolling temperature and a hole is pierced through it lengthwise, forming a seamless tube. The piercing machine has two barrel-like rolls. Between the rolls is a long piercing mandrel with a bullet-shaped nose.



The revolving rolls grasp the white-hot bar stock, spinning it and rolling it over the bullet-shaped piercing mandrel. As the bar moves through the rolls, the piercer goes on through the length of the bar forming a rough pipe without any seam. As is the case with welded pipe, the seamless pipe is put through sizing rolls to reduce it to proper size and make it perfectly round.

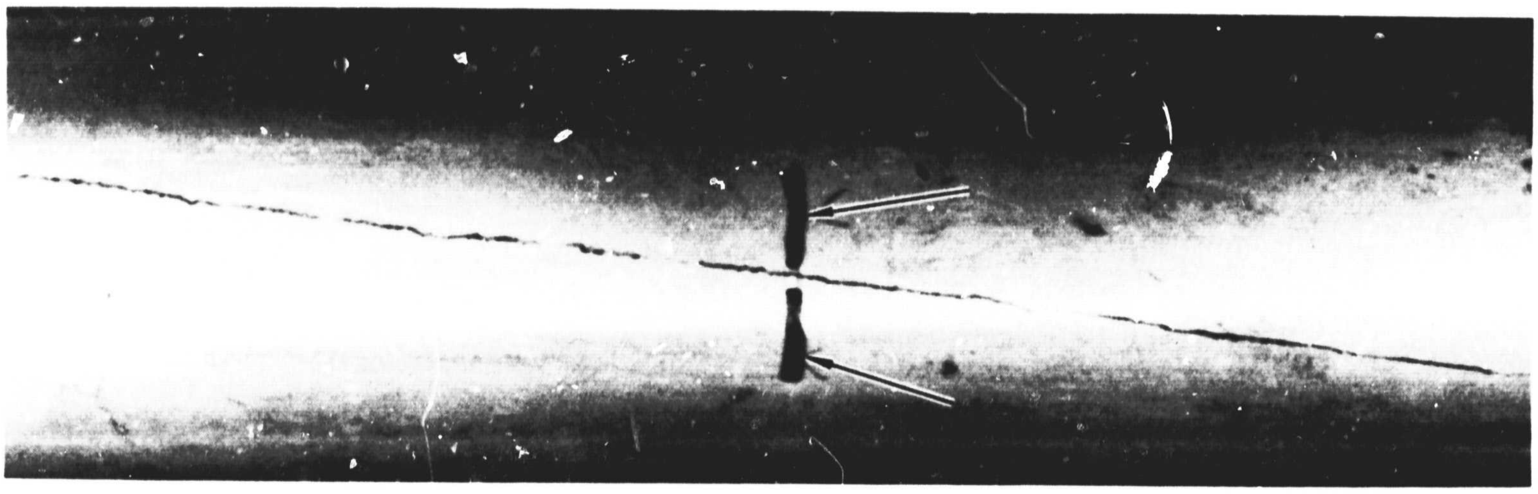
Since seamless pipe is made from round bar stock, which of the following discontinuities could appear on the outside surface of the pipe?

Seam . . . . Page 5-10

Lamination . . . . Page 5-11

From page 5-9

Sure. A crack in a billet would be stretched out into a seam in round bar stock. Since seamless pipe or tubing is made from bar stock, the pipe could certainly have a seam like this one.



Seamless pipe can have discontinuities on the inside of the pipe caused by the piercing mandrel. As the white hot bar stock is spun and rolled over the piercing mandrel, occasionally, some of the metal pieces will adhere to the mandrel. The metal buildup on the mandrel may be torn from the mandrel and fused back into the pipe, gouging a rough depression in the process. The pieces of metal fused into the pipe in this manner are called SLUGS.

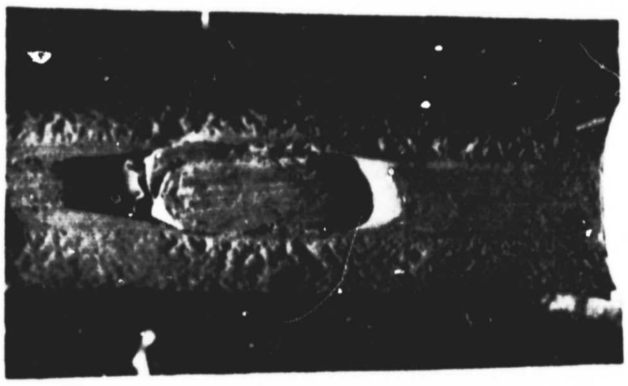
Turn to page 5-12.

You believe that seamless pipe could have laminations. That was the wrong choice. A lamination is found in sheet or plate stock. It is a non-metallic inclusion that is flattened out when a slab is rolled into plate stock.

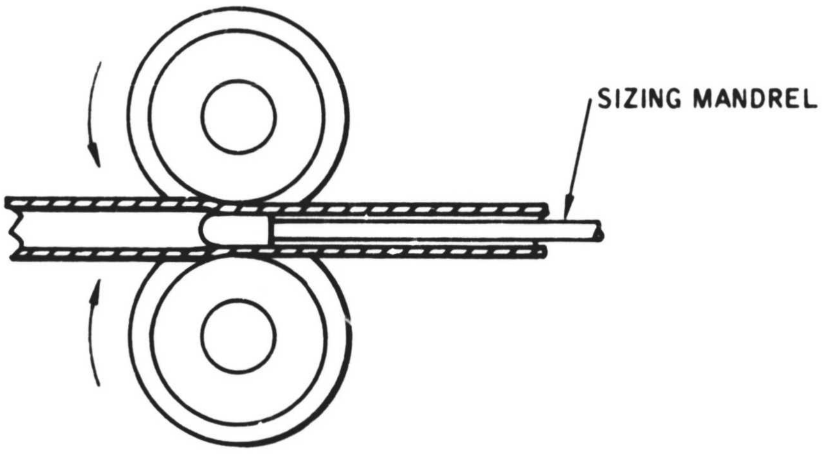
Seamless pipe is not made from plate stock. It is made from round bar stock. This means that it could not have laminations. But round bar stock can have a discontinuity that, after processing, would run longitudinally along the outside surface of the pipe. This discontinuity would be called...

...a seam . . . . Page 5-10

Here is another example of a SLUG found in a liquid oxygen line used for fueling a space launch vehicle.



In some cases, pipe or tubing is put through sizing rolls which have a sizing mandrel between the rolls as shown here.

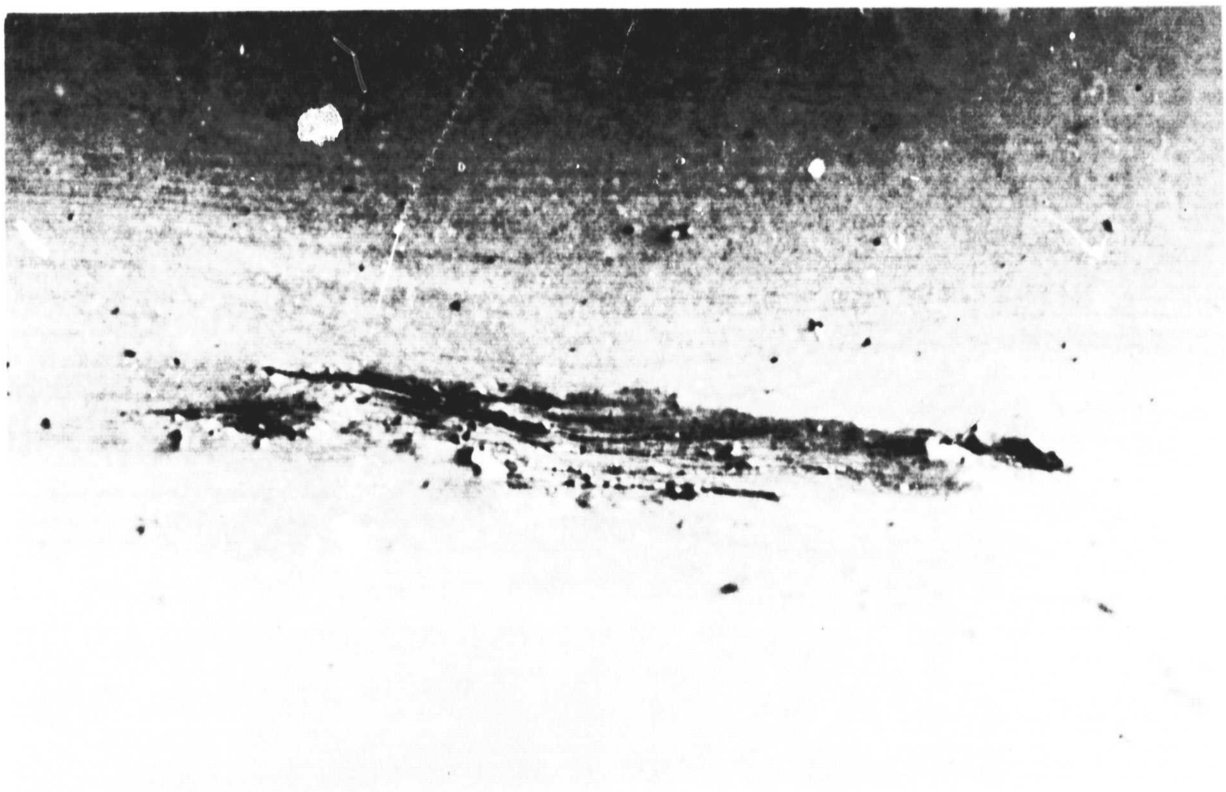


Use of the sizing rolls with the mandrel in between assures that both the inside and outside diameter of the pipe or tubing is perfectly round. Under some conditions, friction between the mandrel and the inside surface of the pipe causes gouging of the inside surface of the pipe.

Turn to the next page.

From page 5-12

Here is an example of gouging on the inside surface of a pipe.



Here is a discontinuity on the inside surface of a piece of pierced pipe.

What is the name of this discontinuity?

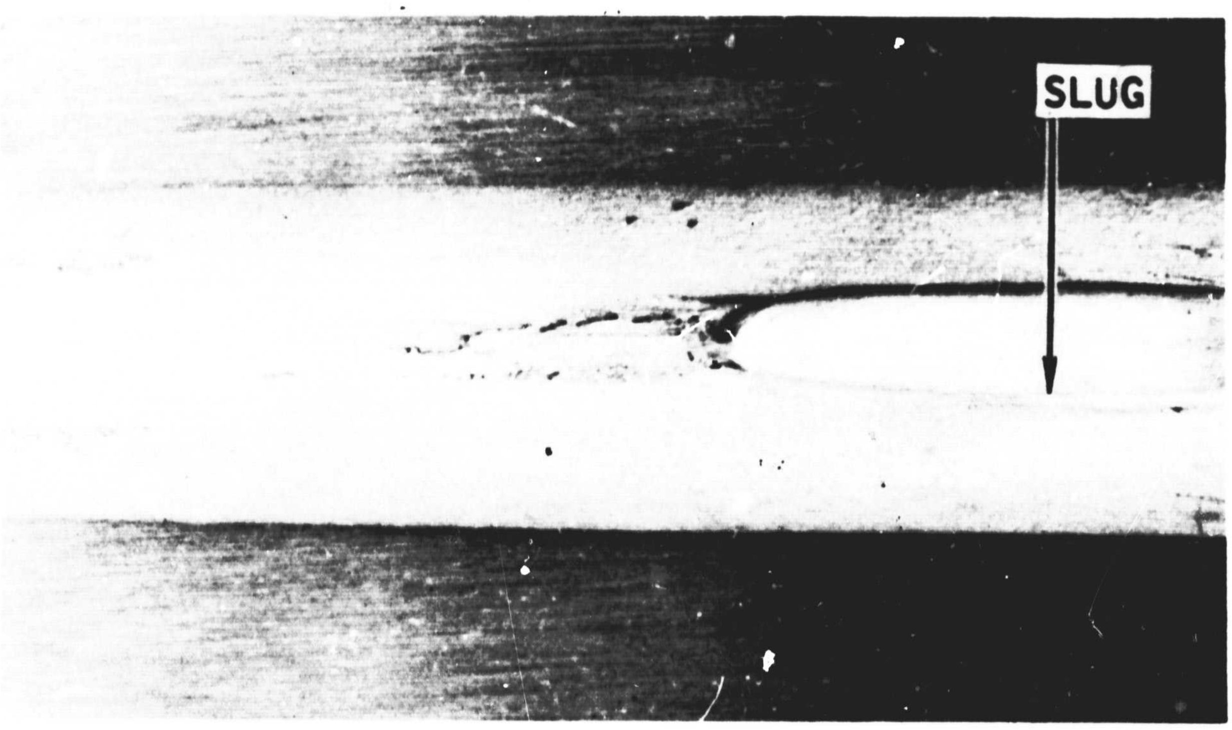
Gouging . . . . Page 5-14
Slug . . . . Page 5-15

From page 5-13

You believe that the discontinuity shown is called gouging. That's partially right. Gouging is caused by friction of the mandrel and inside of the pipe, however in the case shown, a slug has been deposited in the pipe wall as the result of severe metal buildup on the mandrel. A simple gouging action would look more like the one pictured below. The slug would not be present.

Return to page 5-13 and review the photos.

Absolutely. That was a slug in a piece of pierced pipe. It is caused by metal buildup on the piercing mandrel. Here is another example of SLUG.



In summary, WELDED PIPE OR TUBING can have the following discontinuities:

- SEAMS from lack of fusion at the weld.
- LAMINATIONS which may be in the plate stock or skelp from which the pipe is made.

SEAMLESS PIPE OR TUBING can have the following discontinuities:

- SLUGS--caused by metal buildup on the piercing mandrel with subsequent fusing of pieces of the metal to the inner wall of the pipe.
- SEAMS OR STRINGERS--found in the bar stock from which the pipe is made.
- GOUGING--caused by friction between the sizing mandrel and the inside surface of the pipe or tube.

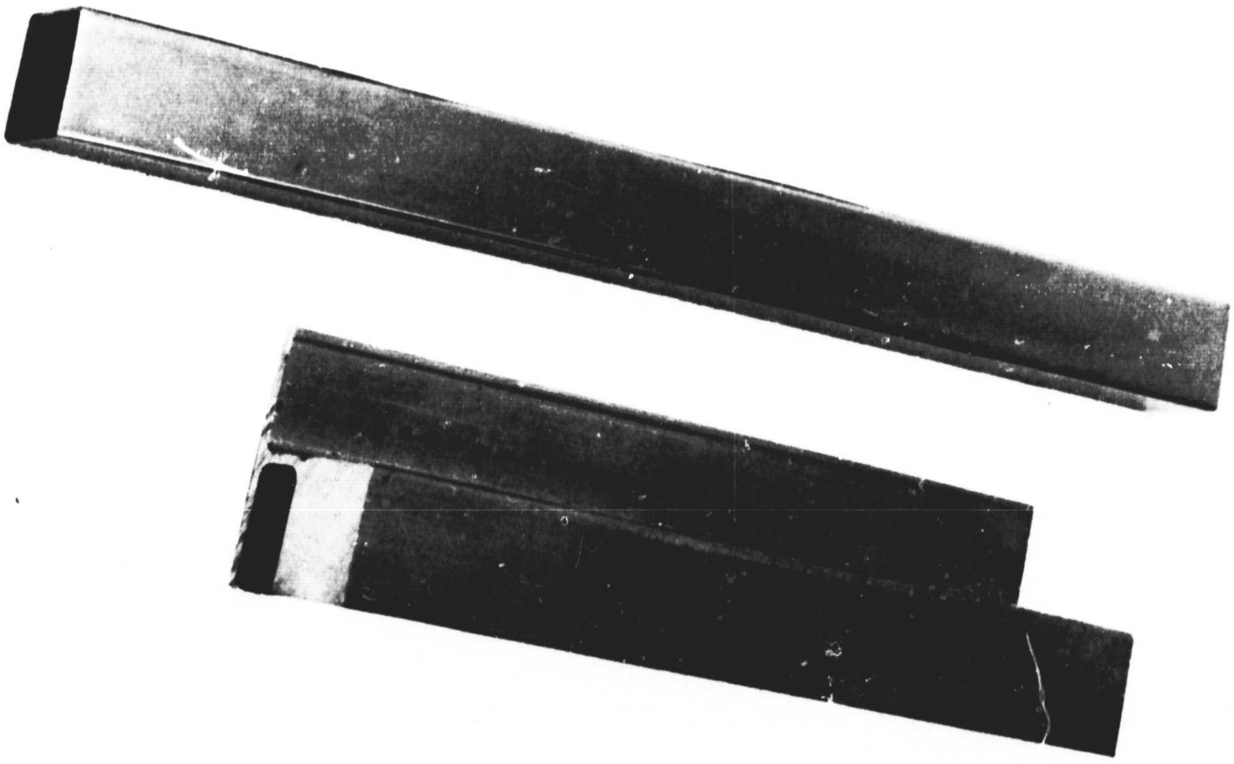
Turn to the next page.

From page 5-15

EXTRUSION DISCONTINUITIES

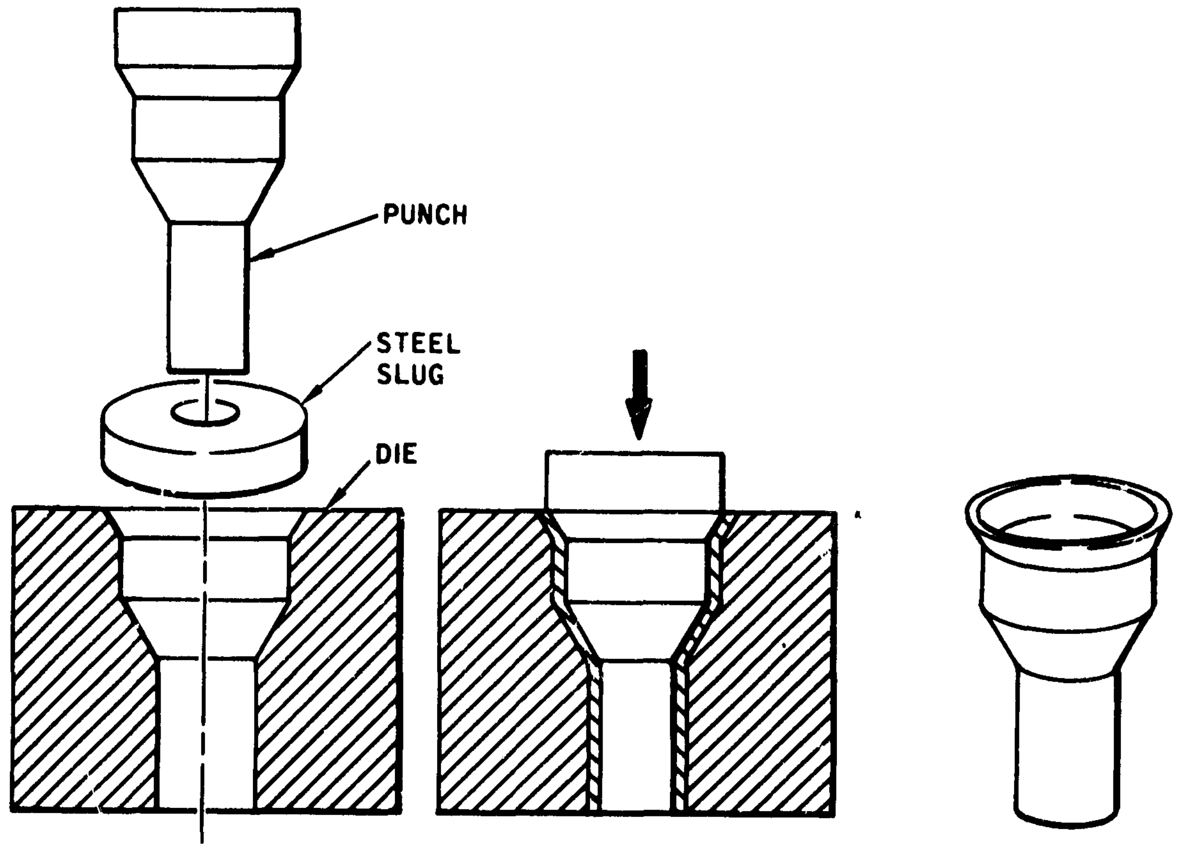
The forming of parts by forcing metal through a die is known as extrusion. Depending upon the manufacturing requirements, the process may use heated metal (hot extrusion) or metal at ambient temperature (cold extrusion). In either instance, the metal, as it is forced into or through the die, takes the cross-sectional shape of the opening in the die.

The extrusion process is adaptable to forming parts from steel, copper, aluminum, and other metals and alloys. The two pieces below are examples of aluminum extrusions.



Turn to the next page.

Let's look at the forming of a soft steel part using a punch to force the metal through the die.



Assuming that the steel slug had been roughed out from bar stock, what types of discontinuities would possibly be in the formed part?

Laminations and hot tears . . . . Page 5-18
Seams and porosity . . . . Page 5-19

No. Laminations and hot tears are not likely to be found in an extruded part formed from steel bar stock.

Laminations occur in processing metal by rolling it into sheet stock. They are non-metallic inclusions which are spread out or sandwiched into sheet stock as it is formed.

Hot tears are normally associated with casting. They occur from the differential cooling of light and heavy sections of a casting.

The point we are trying to make is that it is possible for formed parts to have the same discontinuities as the metal they are formed from. If the original bar stock had contained a crack or porosity, the same discontinuities would show up in the formed part. The part could have...

...seams and porosity . . . . Page 5-19

From page 5-17

Sure. The extruded part we were talking about was formed from bar stock. If the bar stock had contained cracks (seams) or porosity, the formed part would have the same discontinuities.

There are possibilities of discontinuities other than those we associate with the stock from which a part is formed. These can result from the extruding process itself. If the metal does not "flow" through the die properly, there can be cracks or galling in the finished part. This can be the case in either hot extrusions (where the metal must be at a temperature that it can be forced into the desired shape) or in cold extrusions (where the metal must "cold-flow" to form the proper shape).

Nondestructive testing requirements for extruded parts will be determined on the basis of the metal used, the complexity of the part, and other factors inherent in the extrusion process.

Turn to the next page for a quick review of tubing, pipe, and extrusion discontinuities.

From page 5-19.

1. Pipes and tubes are classified in two categories w______________ and s______________.

2. seam

3. A seam in welded tubing may occur either on the i______________ or the o______________ of the tubing.

4. seam

5. Two types of discontinuities that can be caused by the piercing mandrel are s______________ and g______________.

6. Slugs

7. Extruded parts may contain any of the discontinuities found in the ______________ from which they are formed.

1. welded and seamless

2. In welded tubing, a discontinuity caused by lack of fusion in the weld is called a __________ .

Return to page 5-20, frame 3.

3. inside, outside

4. Seamless tubing is made from round bar stock. A crack in the stock would appear as a s__ ______ on the outside of the tubing.

Return to page 5-20, frame 5.

5. slugs, gouges

6. __________ are caused by metal that builds up on the piercing mandrel then breaks off and fuses into the pipe wall.

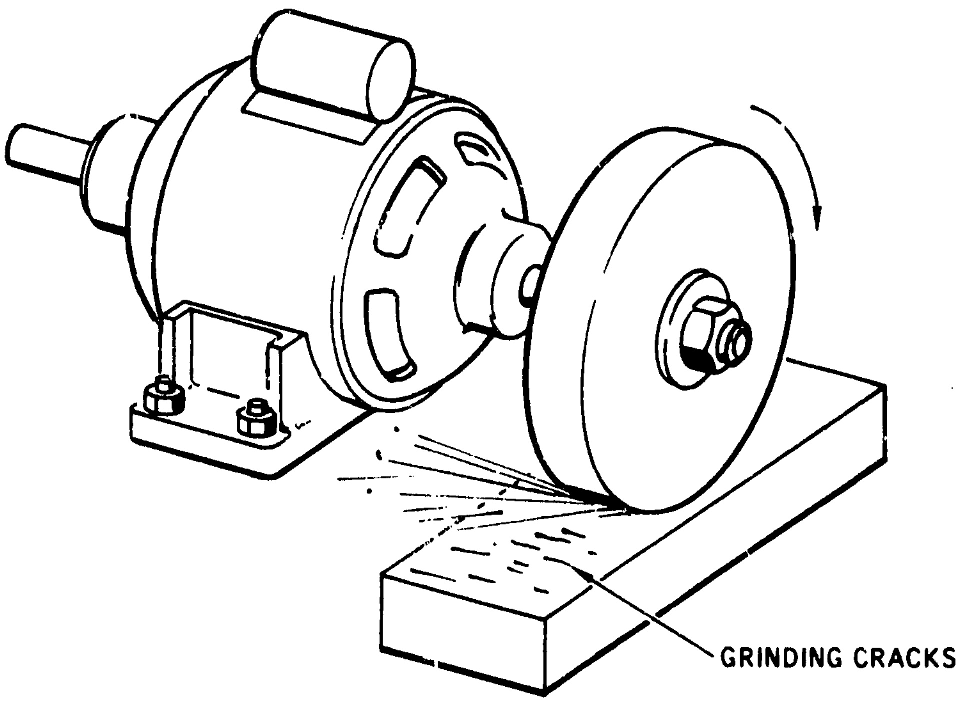
Return to page 5-20, frame 7.

7. metal (stock)

8. Turn to page 6-1.

GRINDING CRACKS

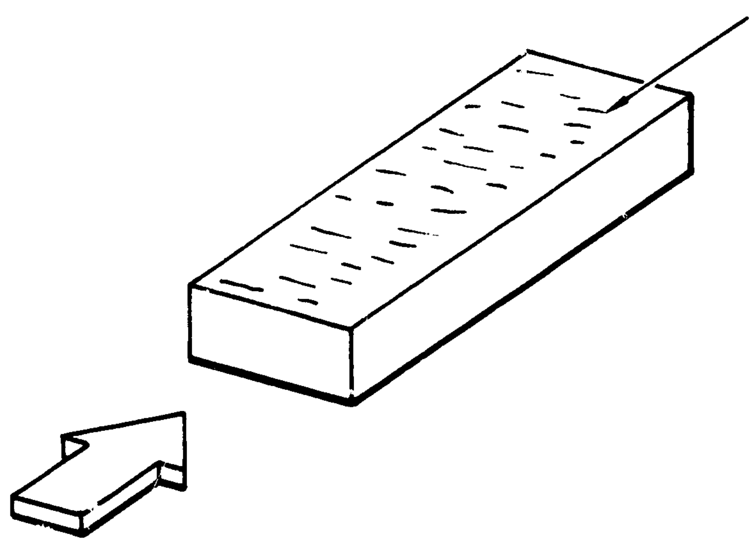
Grinding cracks can be caused by stresses which are built up from excess heat created between the grinding wheel and the metal.



During the grinding of metal, heat occurs at the point of contact between the grinding wheel and the metal. The wheel grinds, heats, and expands the metal directly beneath it. The wheel passes, and the small area which has just been ground, cools and shrinks. According to the illustration above, grinding cracks:

Occur at a right angle (crosswise) to grinding wheel rotation . . . . Page 6-2
Will be found across the grain . . . . Page 6-3

Right. Grinding cracks occur at a right angle (crosswise) to the rotation of the grinding wheel. These cracks have no relation to the grain direction of metal.



When grinding cracks occur they will form at right angles to the direction of wheel r ion. When too much heat is allowed to build up on the surface of the metal being worked, stresses occur. These stresses relieve themselves in the form of cracks.

Very hard heat treated or plated metals are the metals most apt to crack from grinding.

Which is true?

Grinding cracks always go with the grain in hard metals . . . . Page 6-4

Grinding cracks might or might not occur across the grain in hard metals . . . . Page 6-5

Cracks will not necessarily be found across (or with) the direction of the grain because grain direction has nothing to do with crack direction. The picture on page 6-1 indicated that the cracks occurred at right angles or crosswise to wheel rotation. It just happened that in this instance the cracks also went across the grain.

Turn to page 6-2 and continue.

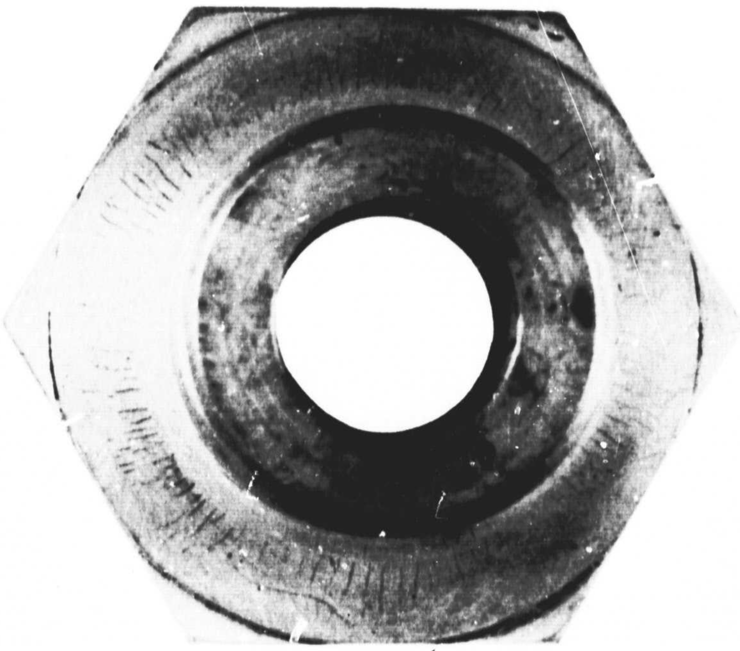
From page 6-2

No, grinding cracks do not always go with the grain in hard metals. Remember, crack direction has nothing to do with grain direction.

Turn to page 6-5.

From page 6-2

Good. Grinding cracks might or might not occur across the grain in hard metals, because grain direction is not a factor governing crack direction. Grinding wheel rotation provided the clue to crack direction since grinding cracks (when they occur) occur crosswise to wheel rotation.



The above illustration shows grinding cracks. Poor grinding technique caused the part to become overheated and the cracks resulted. Any cracks are bad, but the worse the grinding technique, the worse the grinding cracks become. If extreme heat is generated, originally crosswise grinding cracks can extend in many directions forming a lattice-work or checkerboard pattern of cracks.

Turn to the next page.

From page 6-5

HEAT TREATING

Heat treating is, basically, the process of hardening or softening metals by controlled heating and cooling. It is a process by which desired mechanical properties can be introduced into metals. Heat treating, for instance, can be used to give machineability to metal which is to be machined.

We have seen that heat and the processing of steel are closely related. Iron ore is smelted in blast furnaces, castings are poured from molten steel, forging is done on preheated metal. Throughout the steel-making and manufacturing processes steel is heated and cooled, heated and worked, heated and reworked. In each of these steps which produce desired qualities in the metal, there is also the possibility of causing undesirable side effects. These undesirable aspects of metal processing are called:

Discontinuities . . . . Page 6-7
Defect . . . . Page 6-8

Certainly. Discontinuities are what we have discussed, and discontinuities are what we will be seeking in nondestructive testing. They are undesirable aspects of metal processing. In the sense that it can cause discontinuities, heat treating is no different from the other heat using processes.

During the heat treating process stresses are built up which, if not relieved by proper control, will find relief through cracking. A corner, a tool nick, a burr, are examples of possible starting points for heat treat cracks--these provide sharp corners in the metal which act as stress concentration points.

Unlike seams which occur only in the direction of grain flow, or grinding cracks which have their beginning crosswise to wheel rotation, heat treat cracks have no specific direction.

Heat treat cracks might follow the grain or cross the grain . . . . Page 6-9
Heat treat cracks probably would follow the grain . . . . Page 6-10

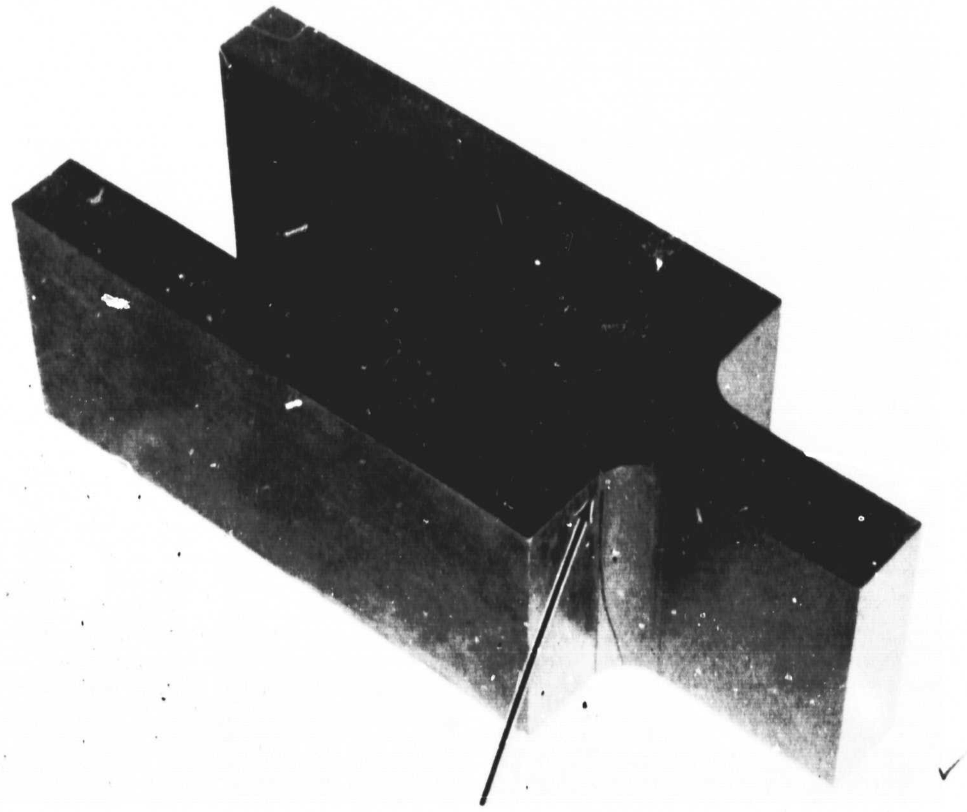
You chose the term "defects" to describe the undesirable aspects of metal processing. This is not the correct term. Although discontinuities might later be labeled defects, depending on several factors, they are first discontinuities; because discontinuities are breaks in metal structure.

Turn to page 6-7.

From page 6-7

Yes, the answer "Heat treat cracks might follow the grain or cross the grain" is merely restating that heat treat cracks have no specific direction.

The photo below shows a part which has cracked from heat treating. Notice that the crack cuts across the grain. Since heat treat cracks have no specific direction, the crack might just as well have followed the grain.



Notice carefully the spot pointed out by the arrow. It indicates that the crack started from a:

Small ridge which had not been machined away. . . . . Page 6-11

Smooth, curved part of the metal . . . . Page 6-12

No, [illegible]nswer that heat treat cracks would probably follow the grain is incorrect. Remember that they occur in no specific direction.

Turn to page 6-9.

Very good. You spotted the small unmachined ridge. The part was improperly heat treated and the ridge acted as a stress concentration point for the crack. Although the ridge was very slight, any sharp area whether small or large, can act as a stress concentration point during heat treating of metal.

Unequal cooling between light and heavy sections of a part which is being heat treated can also result in cracking. As you probably remember this is a result of the property which metal has of:

Occupying more space when hot or molten than when solid or cool . . . . . Page 6-13

Contracting when cold . . . . Page 6-14

This was a difficult one to see and you are certainly not to be chastised for not spotting the very small ridge in the part which acted as a stress concentration point. Nevertheless there is a ridge in the curved area. Return to page 6-9, take another look and even though you might still not see it, turn to the page which indicates that the ridge is there.

From page 6-11

Right. Once again we see that the property which metal has of shrinking as it cools can create discontinuities. Metal occupies more space when hot or molten than when solid or cool. In heat treating the light sections cool faster than the heavy sections which they join and cracks <u>can</u> appear at these light and heavy junctions.

Heat treating then, can cause discontinuities just as can the other metal working and forming processes. During inspection of heat treated parts, the first areas of concern will be:

1. Any sharp area, such as corners, ridges, etc.

2. Junctions of light and heavy sections.

Turn to page 6-15.

Under most circumstances you would be commended for knowing that metal contracts when cold--but not this time. We have made no mention of this fact. We have, however, discussed at length the fact that metal occupies more space when molten than when solidified. The first choice should have been your answer.

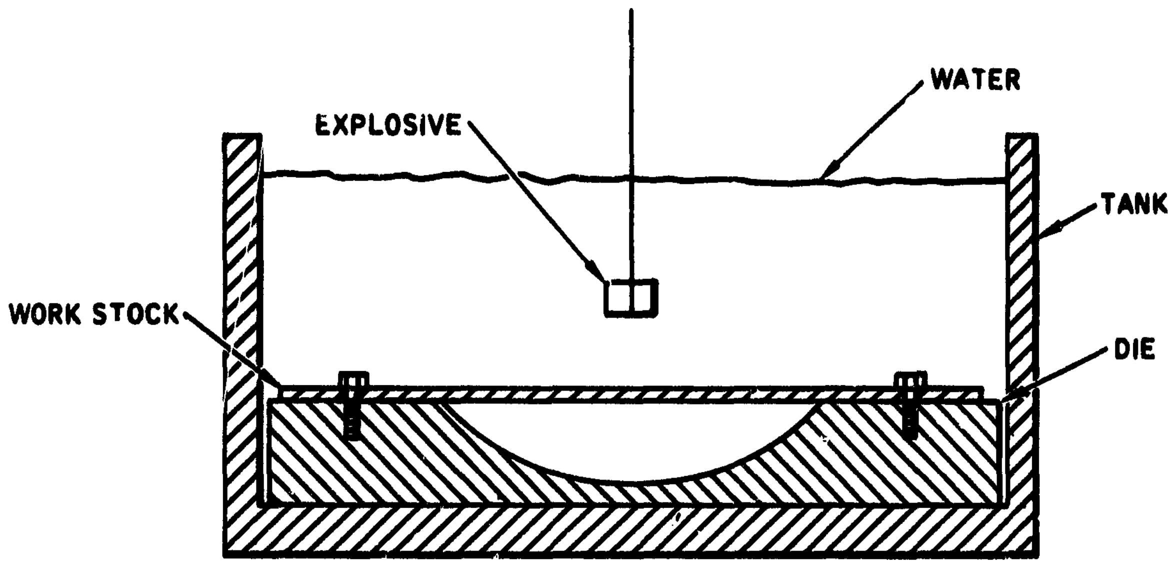
Turn to page 6-13.

From page 6-13

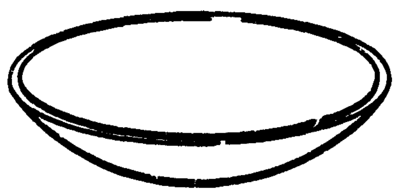
EXPLOSIVE FORMING

Explosive forming is the forming of metal parts in dies where the forming pressure is generated by an explosive charge. The charge is supplied by a variety of explosives ranging from shot gun shells to high explosives such as dynamite.

The forming may be done either in "open air" or submerged in a liquid such as water. In the latter instance, the water supplies a means of transmitting the shock wave of the explosion to the part to be formed. This is illustrated in the simplified illustration below.



The finished part from a cupping die such as the one above (after the flange is trimmed) would look something like this:

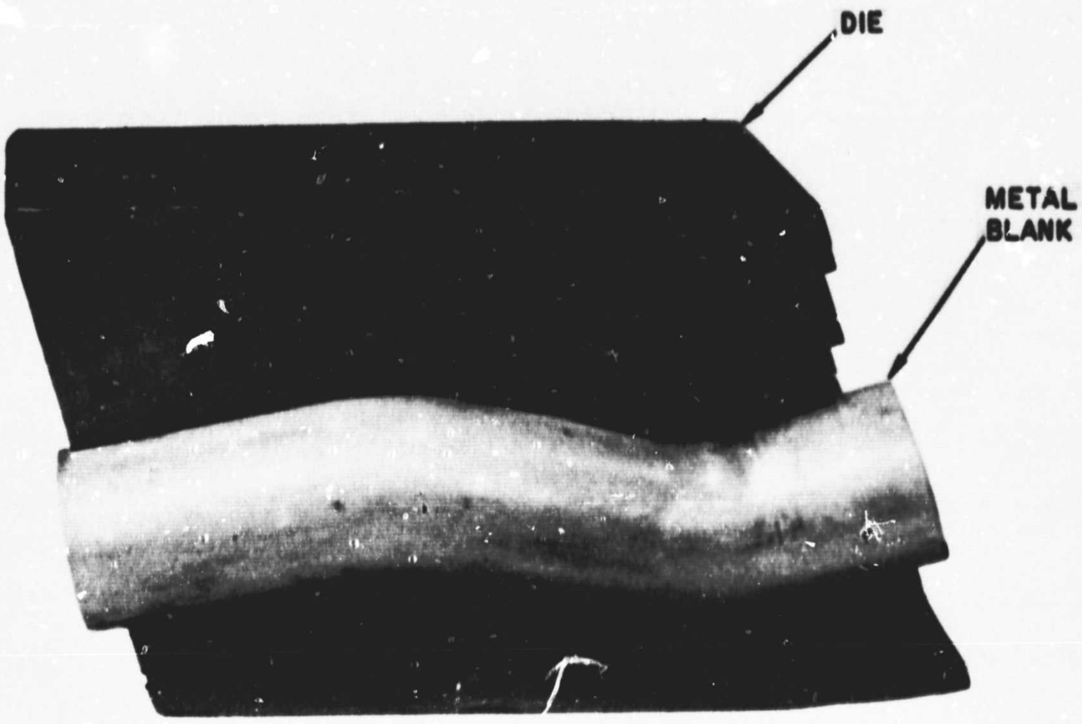


Turn to the next page.

From page 6-15

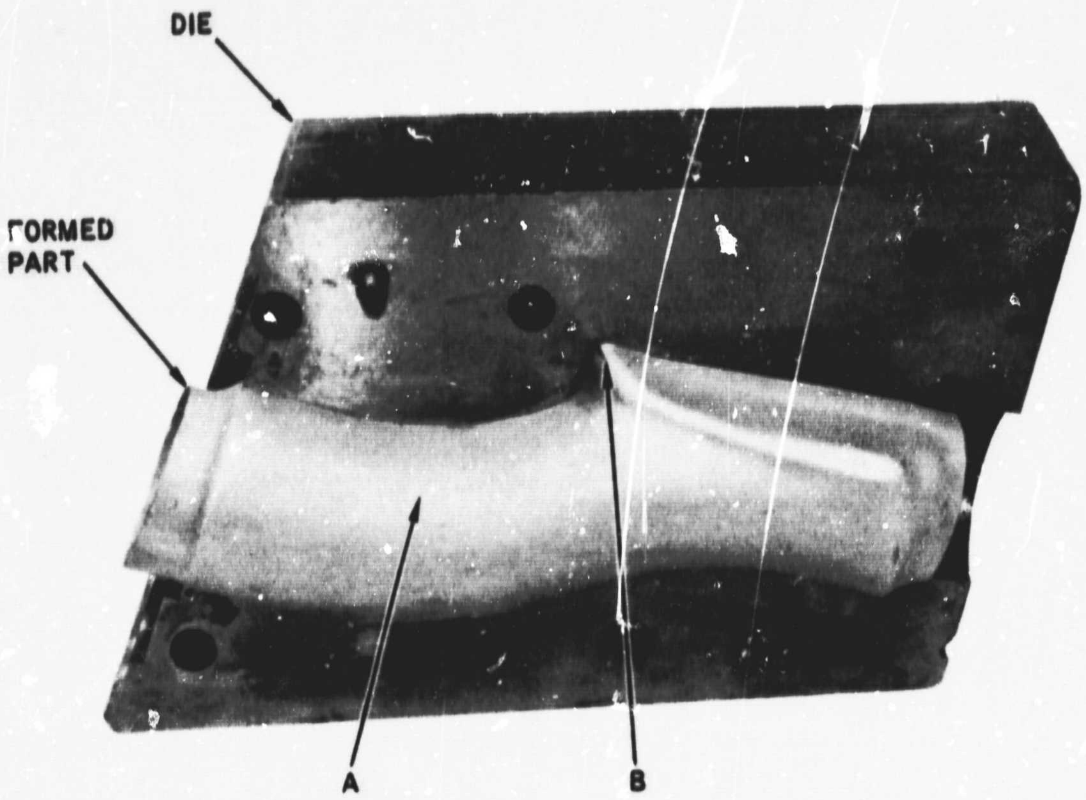
In the illustration on the preceding page, the water transmits the shock wave from the explosive to the stock forcing it into the die to form the desired shape.

The other method of explosive forming (open air) is accomplished without the use of water. It is done by placing charges at strategic locations within a metal blank (such as a tube) that is confined inside a die. The explosion forces the blank to conform to the shape of the die. The photograph below shows one-half of a die with a metal blank inserted for forming.



Turn to the next page.

Now [illegible] take a look at the finished product with the die opened following the explosive forming of the part.

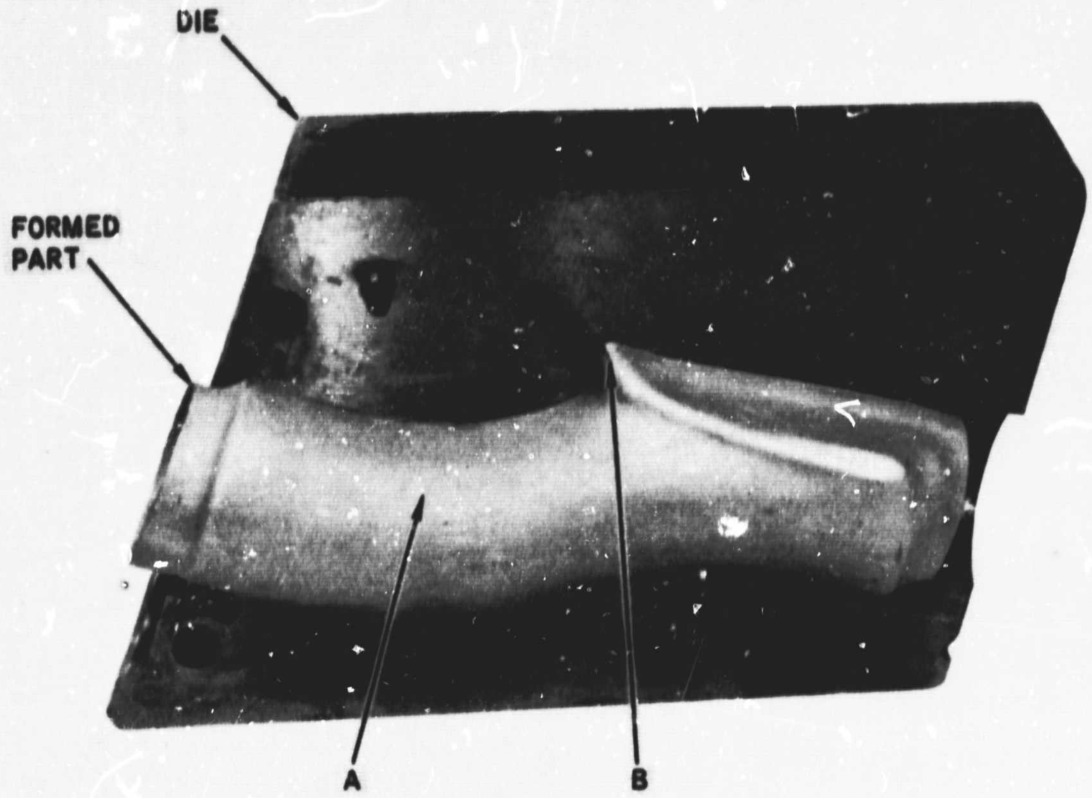


You can see that the explosion caused the blank to conform to the shape of the die. Study the photo carefully. Do you think a discontinuity would most likely occur at point "A" or point "B"?

A . . . . Page 6-18
B . . . . Page 6-19

From page 6-17

You selected "A" as the point at which a discontinuity is most likely to occur. Your selection is wrong. Here is the die and the formed part.

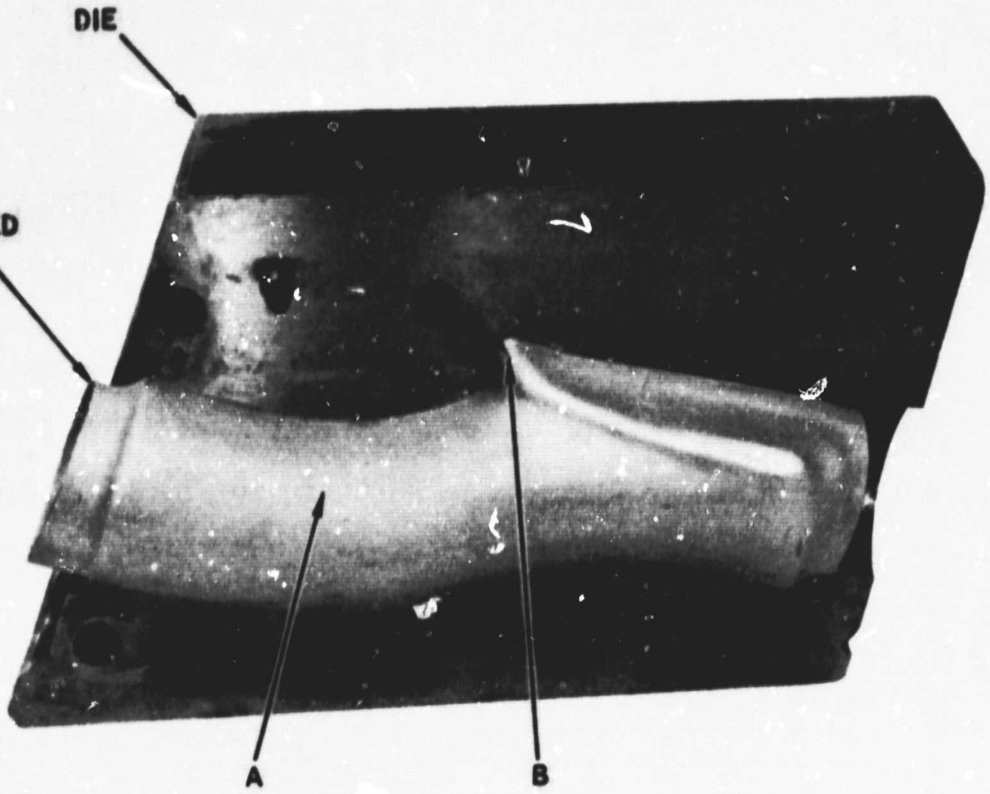


Take another look. Point "A" is in an area where the metal was not greatly affected by the explosion. The metal did not have to be deformed very much at that point to conform to the shape of the die.

By comparison, point "B" is a point at which the metal had to be sharply changed in shape to conform to the shape of the die. In fact, if you take a close look at the formed part, you can detect a crack or tear in the part at point "B."

Turn to page 6-19.

Correct. The part shown is most likely to have a discontinuity at point "B." In fact, if you take a close look, there is a discontinuity at point "B."



The discontinuity is a crack or tear caused when the explosive force overstressed the material while shaping it to the contour of the die. A discontinuity is most likely to develop at a point in the die where the most extreme deforming of the stock occurs - or where the die changes contour abruptly.

Explosively formed parts can have discontinuities caused by stress in the forming, improper die junctions, or ones which existed in the metal stock or blank from which the part is formed.

Our next subject deals with discontinuities in parts which passed former nondestructive testing inspections and which have been in use.

Turn to page 6-20.

FATIGUE CRACKS

Thus far in this book we have discussed steel-making and steel-working processes and have seen how each of these processes can result in discontinuities. Up to this point we have been concerned with the condition and quality of parts and materials before they are placed in service. Now let's look at a discontinuity that can occur in parts and materials which have passed all inspections and have become part of a functioning industrial product.

The role of nondestructive testing is not finished with the placement of these parts in the capacity for which they were intended. For, as can you and I, these metal parts can become fatigued through repeated use and/or overloading. The role of nondestructive testing, therefore, is just as important after the parts are placed in service as before.

Suppose you were conducting a nondestructive test during a maintenance inspection on an airplane. Would you consider the landing gear an area of high stress requiring inspection?

Yes . . . . Page 6-21

No . . . . Page 6-22

Yes, if conducting a nondestructive test on an airplane during a maintenance inspection you would most certainly inspect the landing gear--an area of high stress! Each time the airplane lands the landing gear is subject to high stress. The harder the landing or the heavier the airplane, the greater the stress.

Recently a heavily loaded helicopter collapsed while parked. It was discovered that a landing gear main support beam had sustained a tool nick. The nick (a discontinuity) created an area of stress concentration from which a fatigue crack had formed. The crack progressed slowly through the beam until, without warning it failed and the landing gear collapsed.

Fatigue cracks on highly stressed surfaces (such as the landing gear beam) often start from discontinuities. Nicks, grinding cracks, forging laps, even poorly finished surfaces, are all examples of discontinuities which might result in fatigue cracks.

What is your opinion of porosity or non-metallic inclusions within a highly stressed metal part--could they possibly cause fatigue cracks?

No . . . . Page 6-23
Yes . . . . Page 6-24

You said that an airplane landing gear is not an area of high stress, but it is. The landing gear of an airplane must support the weight of the entire airplane while the plane is on the ground. Additional stress is placed on the landing gear during hard landings.

Turn to page 6-21.

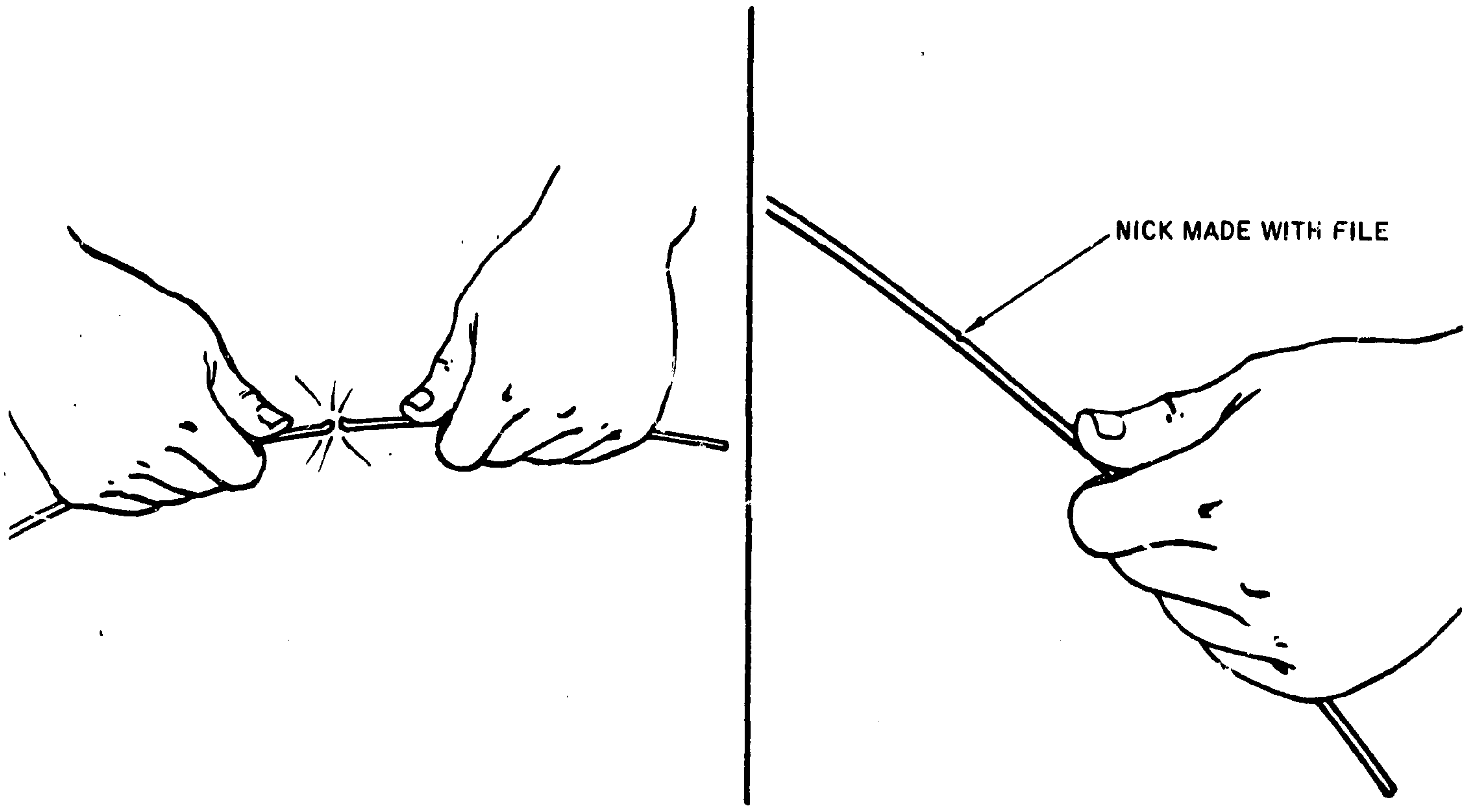
Your answer that "no, non-metallic inclusions or porosity could not possibly cause fatigue cracks," is wrong. Even though most fatigue cracks occur from surface discontinuities, subsurface discontinuities also create stress concentration points and can cause fatigue cracks.

Turn to page 6-24.

Excellent. Porosity or non-metallic inclusions within a highly stressed metal part could certainly result in fatigue cracks. These discontinuities serve as stress concentration points--as starting points--for fatigue cracks.

Although some fatigue cracks might be subsurface (such as those having their beginning from porosity or non-metallic inclusions) most fatigue cracks are open to the surface. Why? Because fatigue cracks usually start from stress concentration points which themselves are open to the surface.

Highly stressed surfaces are surfaces subjected to movements in several directions or heavy loading. A wire bent rapidly back and forth is an example of metal stress.



The wire in the left picture broke after twelve bends. An as yet unbroken wire from the same roll (right picture) has been nicked slightly with a file. The nicked wire will:

Require twelve bends before breaking . . . . Page 6-25

Break before being bent twelve times . . . . Page 6-26

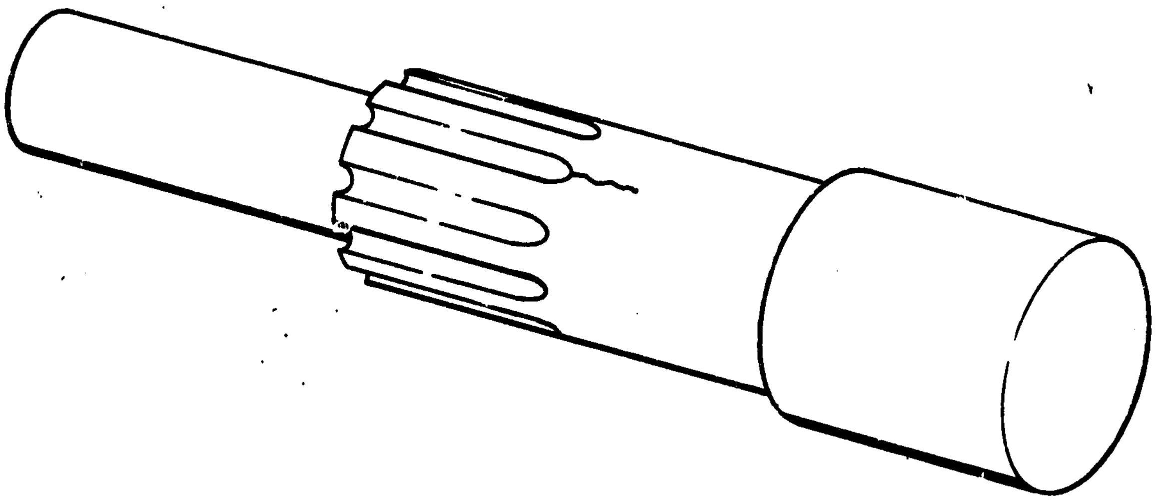
No, the nicked wire would <u>not</u> require the same number of bends (twelve) to break as were required by the un-nicked wire.

Stress will concentrate at the nick in the wire and it will break sooner than did the wire which has no stress concentration point.

Turn to page 6-26.

Right. The un-nicked wire broke after twelve bends. The other wire was given a stress concentration point and the wire will certainly break before being bent twelve times.

Fatigue cracks in functioning parts occur crosswise to the direction of stress movement. The fatigue crack shown in the drive shaft below illustrates this fact. The stress on this shaft would have been clockwise--the direction of its rotation. The fatigue crack occurred across the direction of stress movement.



Fatigue cracks are possible only after a part has gone into service. If undetected they will eventually result in failure of the part and possibly of the entire product to which it belongs. But they can be found through nondestructive testing, just as can those discontinuities which are found in parts and materials during the steel-making and steel-working stages.

For a review of Chapter 6, turn to page 6-27.

From page 6-26.

1. Grinding cracks are one of the easiest types of discontinuities to recognize. They are caused during grinding when too much h______ is created.

5. heat

6. If grinding cracks do occur, however, they have their beginning in a ____________ direction to grinding wheel rotation.

10. direction

11. In addition to sharp corners, nicks, or burrs which act as stress concentration point, junctions between light and heavy sections might cause cracks. These cracks would be the result of unequal c____________.

15. explosive forming

16. Explosive forming of parts is done by using an explosion to force metal to conform to the shape of a ______.

1. heat

2. Grinding cracks will aiways occur cr____________ to the direction of grinding wheel rotation.

6. crosswise

7. Originally crosswise cracks can extend in many directions if the grinding technique is extremely bad. These cracks then begin to form a lattice-work or ____________ pattern.

11. cooling

12. Heat treating is used to produce certain qualities in a finished part. But despite these qualities, however desirable, a part can crack after it has gone into service. These cracks are the result of f____________.

16. die

17. A discontinuity is most likely to occur where the die changes shape abruptly. This discontinuity would be a ____________.

2. crosswise

3. Since grinding cracks occur crosswise to grinding wheel rotation, it is evident they have nothing to do with grain ________________.

7. checkerboard

8. A process which can cause discontinuities while heating metal to cause desirable qualities is called h________ t________________.

12. fatigue

13. Fatigue cracks occur crosswise to the direction of stress. They have their beginnings from nicks, grinding cracks, forging laps, etc. These act as stress concentration points. If a fatigue crack started at a tool nick, it would be ______ to the surface.

17. tear (crack)

Turn to page 7-1 for a discussion of welding discontinuities.

direction

4. Grinding cracks occur ______________ to grinding wheel rotation. But in severe cases they begin to extend in many directions forming a lattice-work or ch______________ pattern.

8. heat treating

9. Heat treating can cause cracks if stress which built up during the process is not properly relieved. These cracks are apt to start at stress concen______________ points such as sharp corners, nicks and burrs.

13. open

14. Even though most fatigue cracks are open to the surface of the parts in which they occur, if they started from a discontinuity such as porosity, they remain sub______________.

Turn to the next page.

crosswise

checkerboard

5. Discontinuities can be prevented during grinding if the creation of too much ______ is not allowed to occur.

Return to page 6-27, frame 6.

9. concentration

10. These heat treat cracks might occur in the direction of the grain or they might run across the grain. In other words, they have no specific d________________.

Return to page 6-27, frame 11.

14. subsurface

15. The forming of metal parts by the use of an explosive charge is called ____________ ______________.

Return to page 6-27, frame 16.

Turn to page 7-1.

Welding technology is closely related to and very important in the nondestructive testing field. A flawless, properly-made weld provides a strong link in the quality assurance chain. A faulty weld can mean failure of part, failure of a system, or failure of an entire program.

There are many types of weldments used in our present space program. The more prominent ones are:

- Tungsten inert gas
- Metal inert gas
- Shielded metal arc
- Electron beam
- Resistance

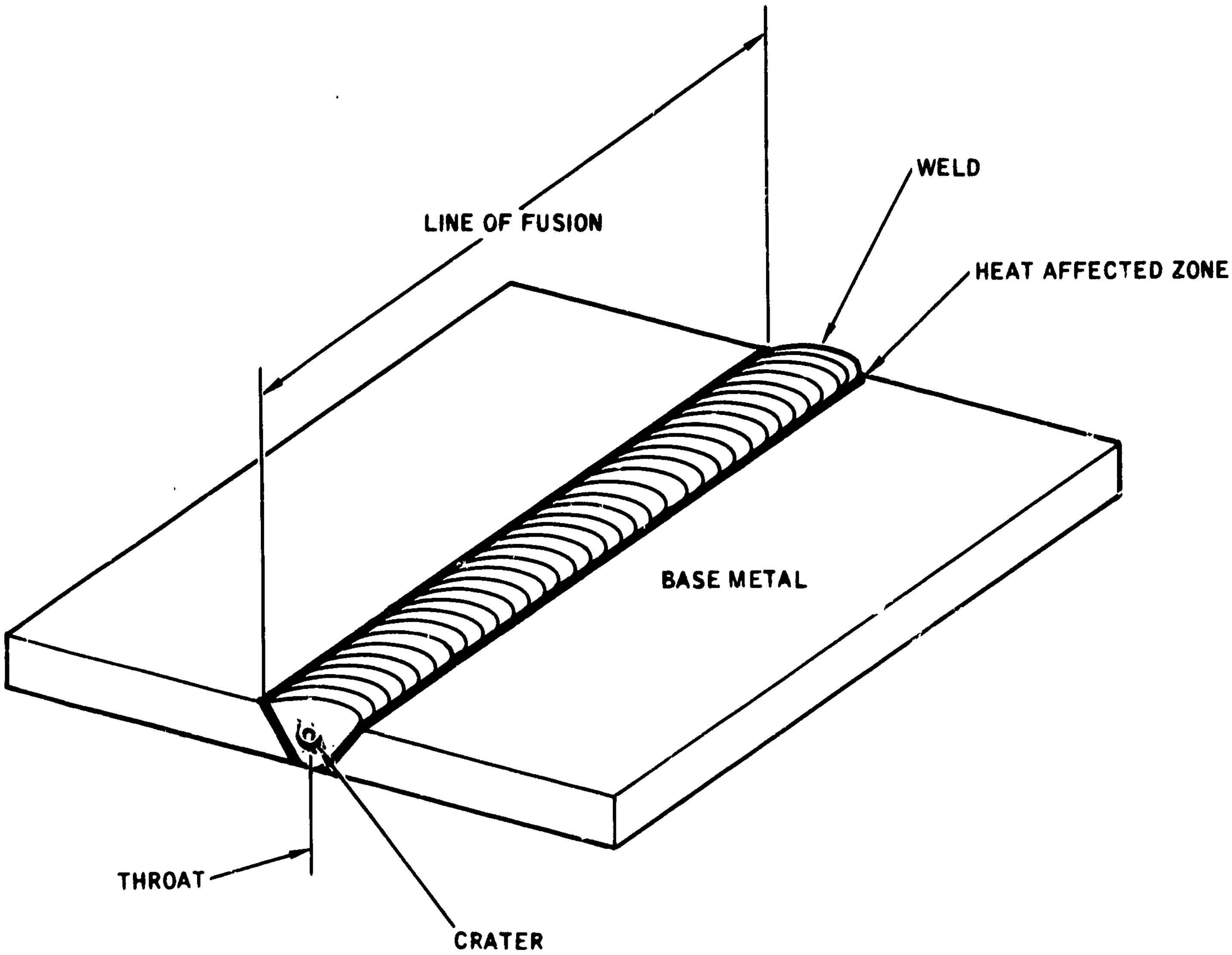
In addition to those welding types listed above, there are various techniques and variations of each of them. It is not our intent to give you a complete cram-course in welding techniques. That would take another few hundred pages. However, you should be familiar with the more common discontinuities found in welds and we will touch briefly on these in this chapter.

Turn to the next page.

From page 7-1

WELDING TERMS

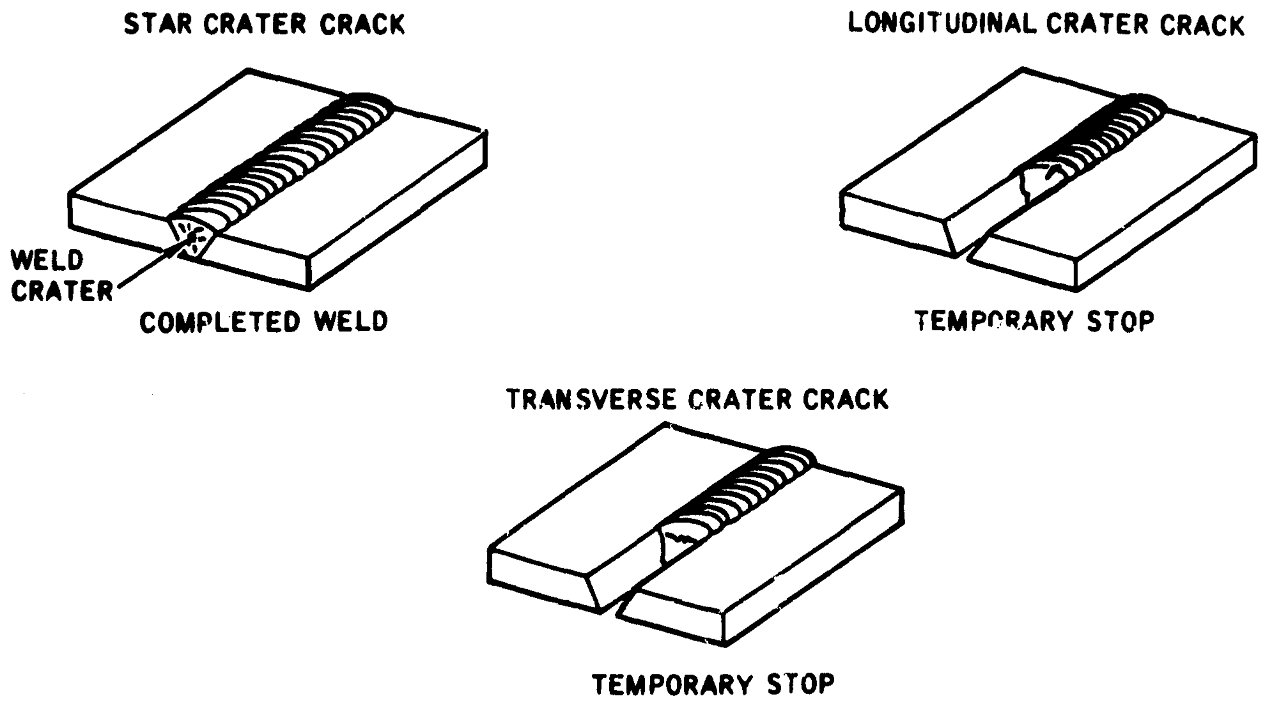
The illustration below shows the typical welding terms which will be used in this section. You may want to mark this page for reference.



Turn to the next page.

CRATER CRACKS

Crater cracks are caused at the weld bead crater by improper use of the heat source either when a weld is started or stopped. The start of a weld and the end of a weld, then, would be obvious places to look for crater cracks. But suppose that a weld was stopped or broken off temporarily. A crater crack could occur at this temporary stop. The illustrations below show welds in different stages of completion. In each of the welds a crater crack has occurred. You can see that these cracks can take different shapes.



The two welds on the right above have not been completed. When the welder takes up his torch or arc to complete the welds, he must take care to fuse the discontinuity together. If he does not completely fuse the metal, a crater crack will remain.

Where <u>might</u> a crater crack in a completed weld be found?

At the end of the weld . . . . Page 7-4
At the beginning of the weld . . . . Page 7-5
Somewhere between the beginning and end of the weld . . . . Page 7-6
At any one, or possibly all, of the above locations . . . . Page 7-7

The answer you have chosen--a crater crack in a completed weld might be found at the end of the weld--is only partially correct. If the heat source was improperly used at the end of the weld, a crater crack might have occurred there.

But the same reasoning applies to the start of the weld and somewhere between the beginning and end of the weld (the weld might have been stopped or broken off temporarily). It depends on whether the heat source was improperly used at these times.

Turn now to page 7-7 and continue with the discusssion.

From page 7-3

You are partially correct in believing that a crater crack might be found at the begin-ing of a completed weld. It would be due to improper use of the heat source.

BUT--the same could also apply to the end of the weld or any stopping point in betwe

Turn to page 7-7 for further explanation.

You are right in thinking that a crater crack might occur somewhere between the start of the weld and the end of the weld--this could happen if there had been a temporary stop somewhere along the weld and improper technique used.

HOWEVER, this answer is only partially correct for the same reasoning applies to the beginning of the weld and the end of the weld.

For the completely correct answer, turn to page 7-7.

Right. In a completed weld, a crater crack might be found at any one, or possibly all, of these locations: at the end of the weld, at the beginning of the weld, somewhere between the beginning and end of the weld.

If the heat source is improperly used at the beginning of the weld, a crater crack can occur. If the heat source is improperly handled at the end of the weld, a crater crack can occur. This stopping point might be at the very end of the metal to be welded or it might occur before the weld is fully completed (a temporary stop). If the weld is not properly fused on restarting, the crater crack will remain.

What about the shape of these crater cracks?

They are all shaped alike . . . . Page 7-8

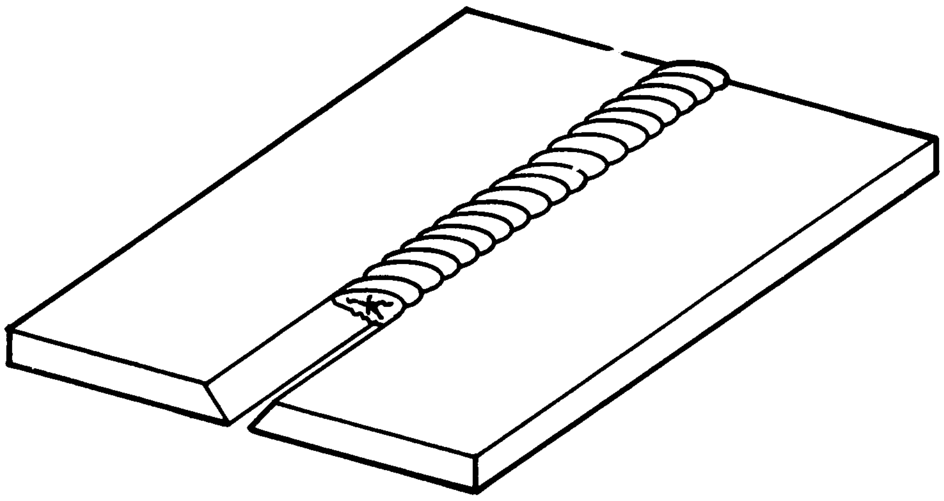
They can have different shapes and directions . . . . Page 7-9

From page 7-7

You are evidently not recalling the crater crack drawings which have been shown, because crater cracks are not all shaped alike and they can and do take different directions.

Turn to page 7-9 for a discussion of these shapes and directions.

Yes, it is a definite fact that crater cracks do have different shapes and directions. This was indicated by the drawings a few pages back. Here is a repeat of one of those drawings showing a crater crack.



The above type of crater crack is given a name which is taken from its general shape.

What is this type of crater crack called?

Transverse . . . . Page 7-10

Star . . . . Page 7-11

Longitudinal . . . . Page 7-12

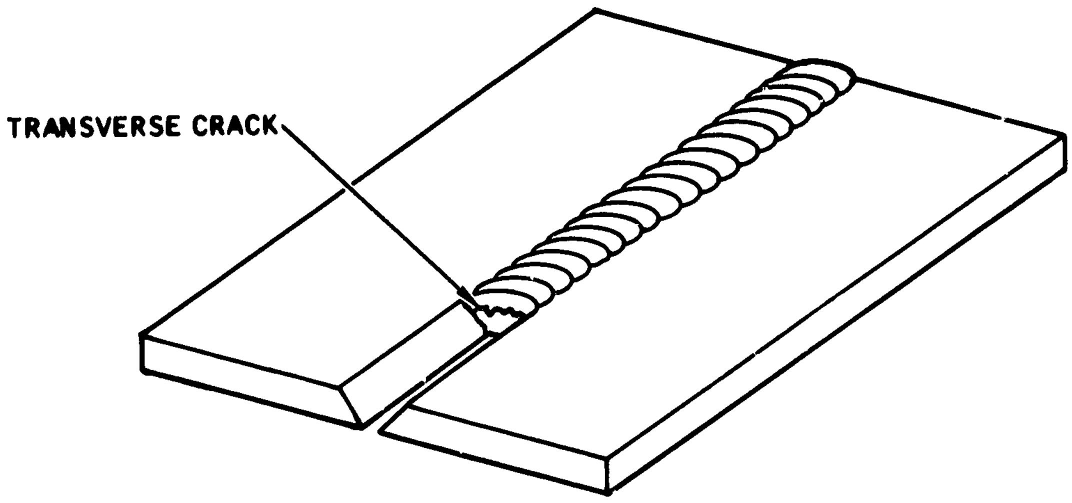
From page 7-9

No, this type of crater crack () is not a transverse crack. Its general shape should give you a clue to its name--STAR crater crack.

However, another of the crater cracks <u>was</u> called a transverse crack. Page 7-11 will recall it to mind.

From page 7-9

Correct, the rough STAR shape ( ) provides the clue to the name of this particular type of crater crack. Three types of cracks have been pictured. Shown below is a TRANSVERSE crater crack.



The reason for the name given this type of crack might not be as obvious as the reason for the name "star." But there is a definite reason for calling this kind of a crack a transverse crack. The reason can be found in the first part of the word--TRANSverse.

Trans simply means across. Recall to mind the word transocean. It means across the ocean. Transatlantic means across the Atlantic.

Take another look at the transverse crater crack above. A transverse crater crack is a crack which:

Penetrates deeply into the weld . . . . Page 7-13

Runs across the crater . . . . Page 7-14

From 7-9

You chose to call the crater crack which is shaped like this () a longitudinal crater crack. That is not its correct name. A careful look at the shape of the crack should tell you that it is a STAR crater crack.

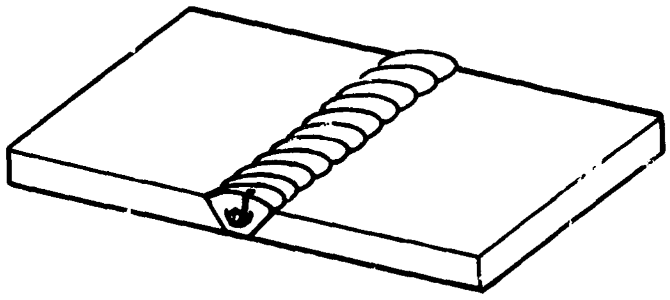
There is a type of crater crack which <u>is</u> termed longitudinal and it will be discussed shortly. But for now turn to page 7-11.

A transverse crater crack might or might not penetrate deeply into the weld but that isn't the correct answer. Remember that we have talked about the first part of the word <u>trans</u>verse. The first part--means across. A transverse crater crack, then, is a crack which runs <u>across</u> the crater.

Turn to page 7-14.

R[illegible]. Transverse means to go across and that is exactly what a transverse crater crack does--it goes across the crater - from side to side.

Star and transverse cracks have been discussed. Now for the third type of crater crack which might be caused by improper use of the heat source--LONGitudinal crater cracks.



Once again the name of the crack plays an important part in picturing and remembering the type of crack. The name "star" referred to the roughly star-shaped crater crack. The term transverse tells you that this type of crack goes across the weld. Now! The word longitudinal tells you that longitudinal crater cracks:

Occur in the long direction of the weld . . . . Page 7-15

Occur in a straight line . . . . Page 7-16

From page 7-14

Excellent! You have correctly determined that the key to the characteristics of a longitudinal crater crack is in the first part of the word--LONGitudinal. A longitudinal crater crack goes in the long direction of the weld, not across the weld or in a star shape.

So what's in a name? In these cases a lot's in a name.

CRATER CRACKS

1. Star. A roughly star-shaped crack.

2. TRANSverse. Trans or across the weld.

3. LONGitudinal. Goes in the long direction of the weld.

The terms transverse and longitudinal can be applied to any weld cracks which occur in the directions (across or long) indicated by those names.

Although a transverse crater crack is limited to the area of the crater and is caused by improper heat source control, any crack that runs across the weld, regardless of the cause, is called a transverse crack.

The same holds true for a longitudinal crack. Any crack that parallels the direction of the weld bead is a longitudinal crack.

Turn to page 7-17 for a discussion of stress cracks.

The word longitudinal does not tell you that this type of crack occurs in a straight line. But it does tell you that it occurs in the long direction of the weld bead.

Turn to page 7-15 and see why.

From page 7-15

<u>STRESS CRACKS</u>

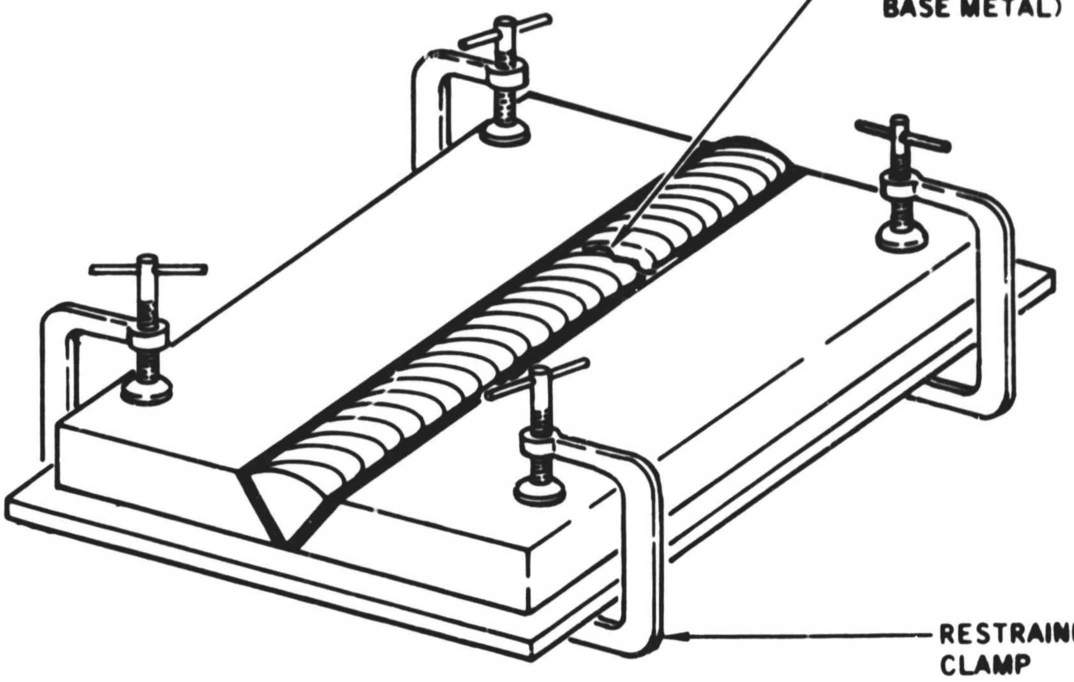
Stress cracks in welds are the result of stresses created during the cooling of a restrained (rigid) structure.

When the two pieces below were welded, the ends were joined and heated until they were molten. The molten material welded together and was left to solidify, joining the two pieces as one. As the molten metal cooled, it began to shrink, creating stress. The pieces were not restrained so the stress relieved itself by pulling the two pieces up to form a "bow," rather than cracking. The "bow" can be removed later so it is no problem.

If each end of the above two pieces had been restrained by clamps, the metal would not have been able to relieve shrinkage stress by bowing and might have cracked as shown on the next page.

Turn to page 7-18.

From page 7-17



Stress cracks might occur anywhere along the weld bead, starting in the weld bead and working their way into the heat affected zone of the base metal. These cracks usually occur transverse to the weld in a single pass weld and longitudinal in a multiple pass weld.

In a weld which is allowed to bow the risk of stress cracks is avoided. However, there are circumstances in which the welding of two stationary pieces is necessary to minimize distortion. An instance in which a stationary weld is unavoidable might be the welding of a catwalk which is already firmly attached to another structure.

A crack in a single pass weld such as the one just described, would usually occur:

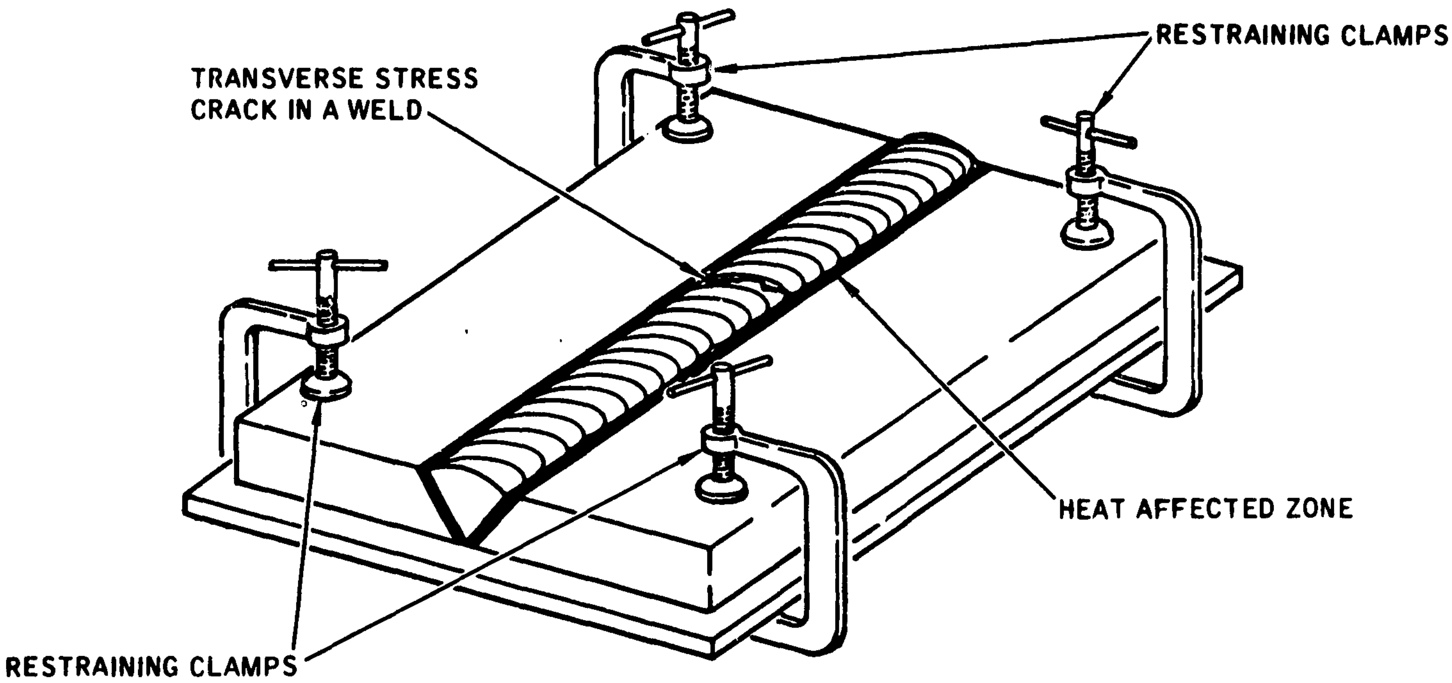
Transverse to the weld . . . . Page 7-19

In a longitudinal direction . . . . Page 7-20

From page 7-18

Yes. The stress crack would usually occur transverse (across) the weld. Notice we said "usually." The pattern is not exact. The stress crack could occur in a longitudinal or nearly longitudinal direction even in a single pass weld.

A crack will often progress from the weld into the "heat affected zone" of the base metal. The heat affected zone is a narrow part of the base metal on each side of the weld. It is that part of the base metal which is altered to some degree by the heat of the welding process.



You can see by the above picture that the transverse crack has extended into the heat affected zone of the base metal.

However, some cracks run in the same direction as the weld. What are these cracks called?

Longitudinal . . . . Page 7-21

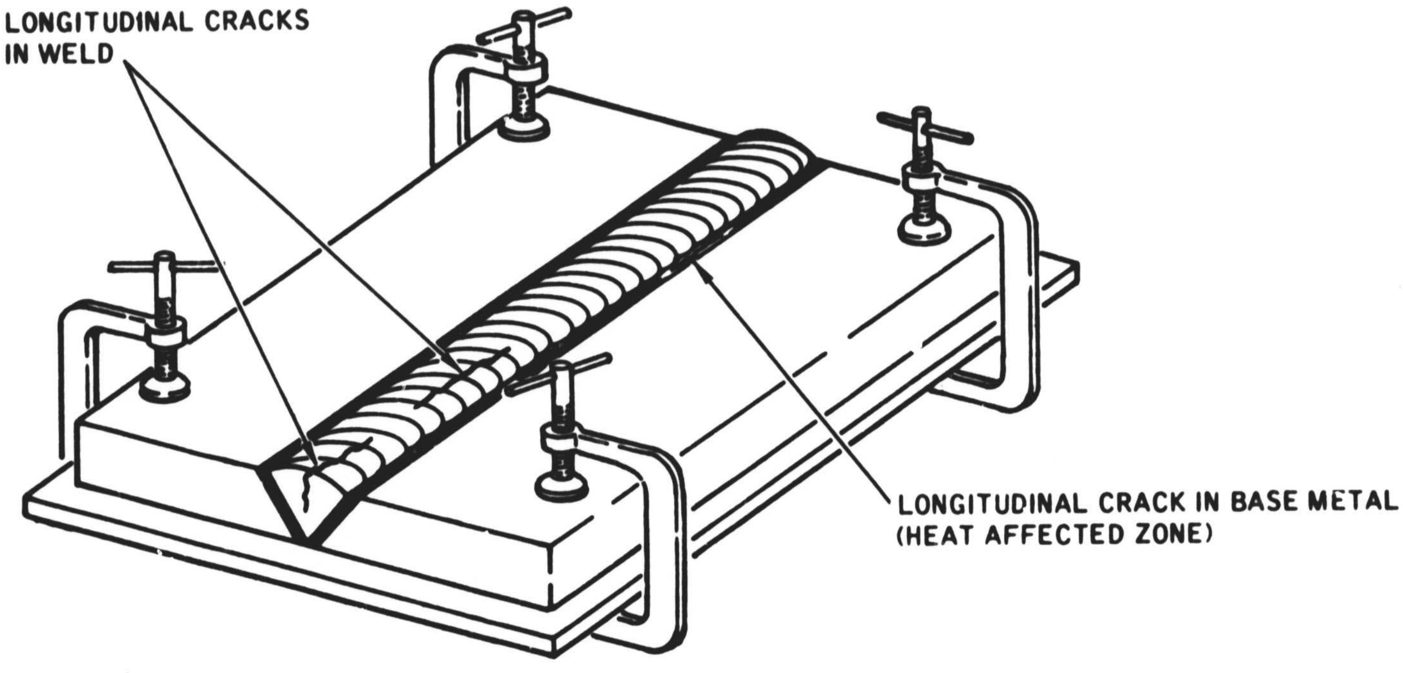
Diagonal . . . . Page 7-22

From page 7-18

If [illegible] stationary (restrained) pieces are welded by a single pass and the stresses cause a crack, the crack would usually occur in a transverse, not longitudinal, direction.

Turn to page 7-19.

Of course a crack which runs in the same (long) direction as the weld is a longitudinal crack. It would look something like the ones pictured below.



Regardless of the cause of stress cracks in or near welds, it is important to know they can and do occur. It is equally important to know that:

1. Transverse cracks go across the weld.
2. Longitudinal cracks occur in the direction of the weld.

Turn to page 7-23 where another discontinuity which occurs in welds is discussed.

From page 7-19

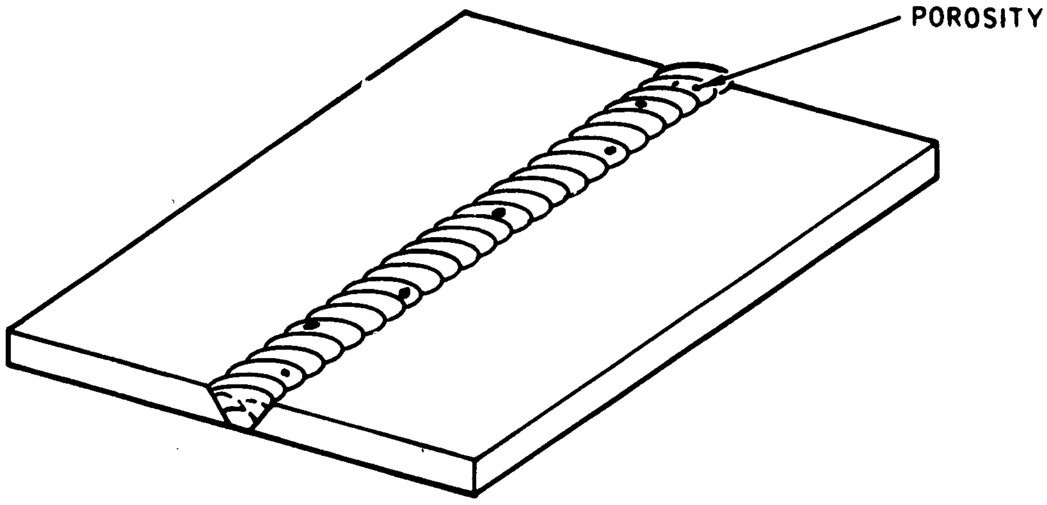
Cracks which occur in the same direction as the weld bead are called longitudinal cracks. The word "diagonal" isn't very descriptive of a crack that runs in the long direction.

Turn to page 7-21.

From page 7-21

POROSITY

Porosity you will remember from the section on ingots, is entrapped gas. The same action which occurred in the ingot occurs on a smaller scale in the molten weldment — entrapped gas tends to rise toward the surface. If any of this gas remains entrapped in the weld it is (as in the case of the ingot) called POROSITY.



Entrapped gas would look like which of the following?

Ragged, irregular discontinuities . . . . Page 7-24

Round or nearly round discontinuities . . . . Page 7-25

From page 7-23

No, porosity would not appear as ragged, irregular discontinuities. Porosity is entrapped gas. As was stated in the discussion on ingots, porosity has a bubble shape — round or nearly round.

Turn to page 7-25.

Right. Porosity in a weld would appear as round, or nearly round discontinuities. Porosity may be open to the surface or it may be subsurface, depending on whether the gas was trapped by the solidifying metal.

Another discontinuity which might be found in welds is similar to a non-metallic inclusion but is called slag inclusions.

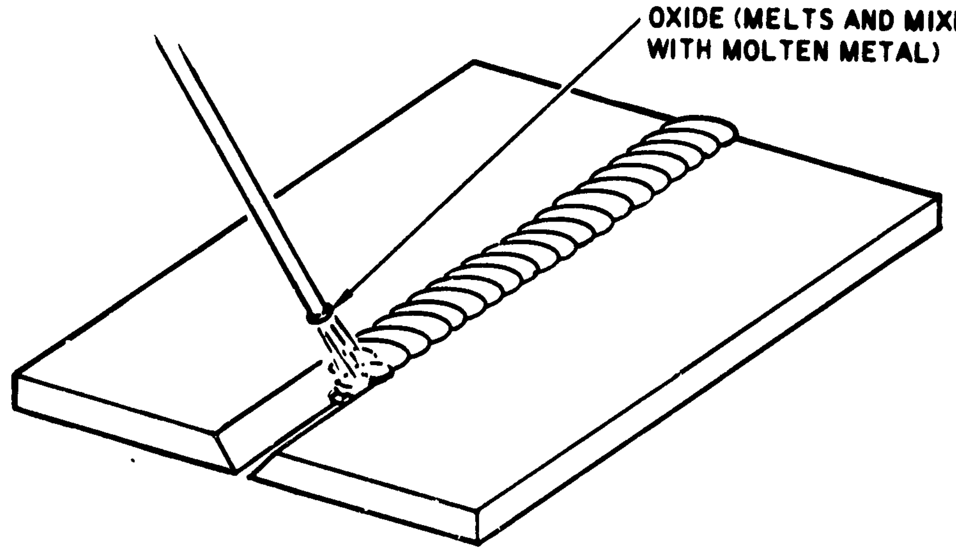
Turn to page 7-26.

From page 7-25

SLAG INCLUSIONS

You will recall that slag in the original steel-making process was a source of unwanted impurities within the steel. Slag inclusion in welds are the same thing — unwanted impurities within the weldment.

Slag inclusions can occur during arc weldi... As the electrode melts so does its oxide coating and it mixes with the molten metal.



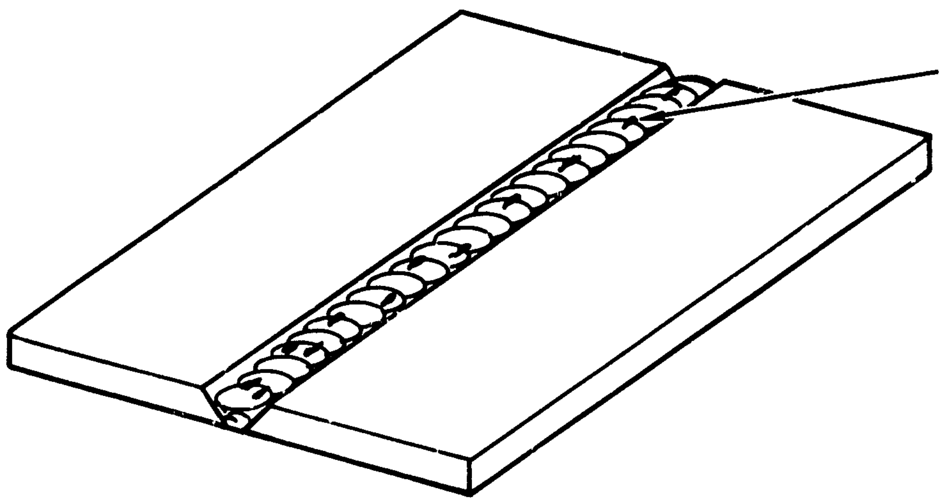
These oxide impurities react as did non-metallic impurities in a molten ingot.

They rise toward the top of the molten metal . . . . Page 7-27

They all remain in the weld . . . . Page 7-28

Of course — these impurities rise toward the top of the molten weldment. When these impurities reach the top of the puddle they harden and form a crust of slag. This slag must be completely cleaned away before the welder makes another pass.

It is probable that much of this slag which is not cleaned off will be trapped (included) in the next layer of metal. The result in the weld bead is SLAG INCLUSIONS.



You can see from the above picture that slag inclusions in a weld:

Occur only in one direction . . . . Page 7-29

Have no definite direction . . . . Page 7-30

From page 7-26

You have answered that all slag inclusions remain in the weldment. That isn't so. It was stated that slag inclusions react as did non-metallic inclusions in an ingot. In other words slag inclusions rise toward the surface of the molten metal.

Turn to page 7-27.

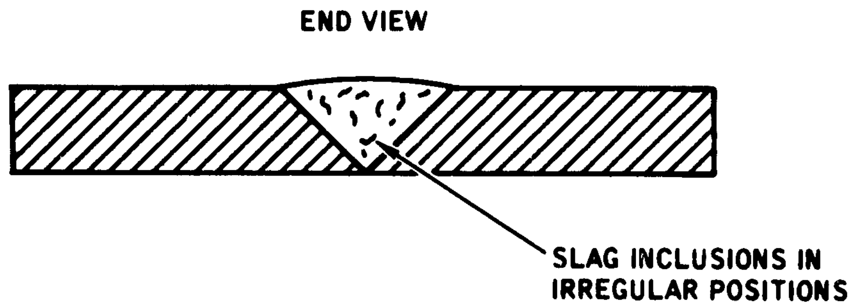
From page 7-27

You stated that slag inclusions occur in only one direction. This isn't so, they occur in all sorts of positions.

Turn to page 7-30.

From page 7-27

Correct. Slag inclusions in a weld do not have a definite or specific direction. They were in the act of rising to the surface but the metal solidified before they reached the surface, trapping them in various positions.



TUNGSTEN INCLUSION

There is another type of inclusion which might be trapped in a weld. Excessive current during tungsten-arc welding can cause the tungsten electrode to melt. When this tungsten is deposited in the weld, a "tungsten inclusion" is created.

The name itself tells you that <u>tungsten inclusions</u> are:

Open to the surface . . . . Page 7-31

Subsurface . . . . Page 7-32

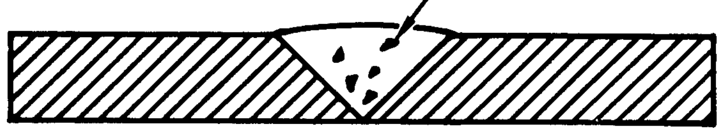
From page 7-30

Although some tungsten inclusions might occur at the surface of a weld, most often they are <u>subsurface</u> discontinuities and <u>are not</u> open to the surface.

Turn to page 7-32 for a look at these tungsten inclusions.

From page 7-30

Go[illegible] the word "inclusions" in TUNGSTEN INCLUSIONS tells you that these discontinuities are <u>sub</u>surface. The inclusions are pictured below.



From the picture above you can see that the inclusions are subsurface and, like slag inclusions, have no definite direction.

The discontinuities pictured above are the result of bits of the electrode being deposited in the molten metal during the welding process.

The electrode was made of:

Oxide . . . . Page 7-33

Tungsten . . . . Page 7-34

These discontinuities which result when melted bits of the electrode are deposited in a weld are called <u>tungsten inclusions</u>. So the electrodes are made of tungsten — not oxide. Oxide can cause a discontinuity but it would be called a <u>slag</u> inclusion. Remember?

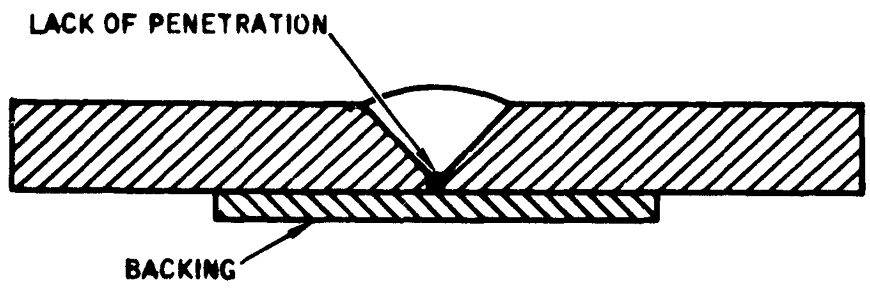
Turn to page 7-34.

Certainly. Tungsten inclusions get their name from the contaminating metal that caused them. The electrode is made of <u>tungsten.</u>

LACK OF PENETRATION

Inclusions, cracks and porosity are not the only discontinuities to look for when inspecting welds. Bad welding technique can result in a discontinuity called "lack of penetration."

Lack of penetration or incomplete penetration is exactly what the name says — a failure of the molten metal to fuse with the parent metal or the backing insert.



The situation shown above might have been caused from too much speed during the welding process. Or, it might have been caused by one of several other reasons. Whatever the cause, when lack of penetration is present:

It occurs at the top of the weld . . . . Page 7-35

It occurs at the root of the weld . . . . Page 7-36

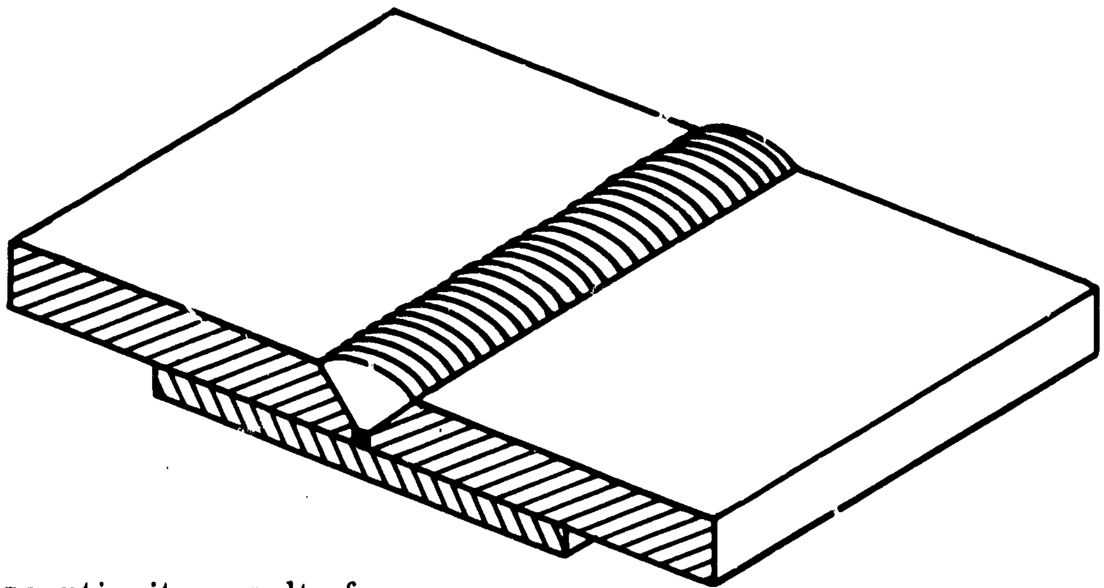
From page 7-34

You will <u>not</u> find lack of penetration present in the top of the weld. If this condition is present, it means that the molten metal has not fused (welded) with the base metal or the backing insert. LACK OF PENETRATION, if it occurs, will be found in the root of the weld.

Turn to page 7-36.

From page 7-34

Lack of penetration is a discontinuity which can occur at the root of a weld, of course. For one reason or another the molten metal did not penetrate to the backing placed at the root of the weld.



The above discontinuity results from:

Lack of backing . . . . Page 7-37

Root condition . . . . Page 7-38

Lack of penetration . . . . Page 7-39

From page 7-36

The term for the discontinuity pictured on page 7-36 is not lack of backing. Part of the problem is that the molten puddle did not penetrate the backing, but the word backing has nothing to do with the name of the discontinuity.

Return to page 7-36 and select another answer.

From page 7-36

The discontinuity on page 7-36 does occur at the root or bottom of a weld but it is not called "root condition."

Return to page 7-36 and select another answer.

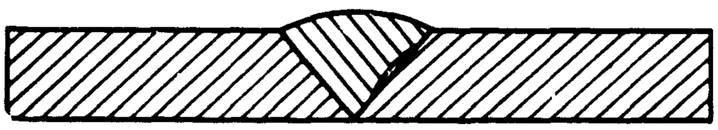
From page 7-36

Lack of penetration is the correct term for the discontinuity just pictured, correct! It results from incomplete penetration into the parent metal, or backing, by the molten puddle.

LACK OF FUSION

A similar condition, but one which occurs further up than the root, is another "lack" known as "lack of fusion."

When a lack of fusion is found it will look something like this:



You can see that lack of fusion is a failure of the weld to fuse with the:

Line of demarcation . . . . Page 7-40

Parent metal . . . . Page 7-41

From page 7-39

Backgouges. Nothing has been said (and nothing will be said) about line of demarcation. It has nothing to do with our welding discussion. Parent metal, however, is and has been a vital part of the discussions. The parent metal is the metal which is being welded together. You now know what the correct answer is but turn back to page 7-39 for another look at LACK OF FUSION before proceeding.

From page 7-39

Right! Lack of fusion is a failure of the weld to fuse with the parent metal. Sometimes the lack of fusion might occur between the weld passes. In either case the discontinuity is termed LACK OF FUSION.

It occurs:

At the root of the weld . . . . Page 7-42

Farther up in the weld than the root . . . . Page 7-43

From page 7-41

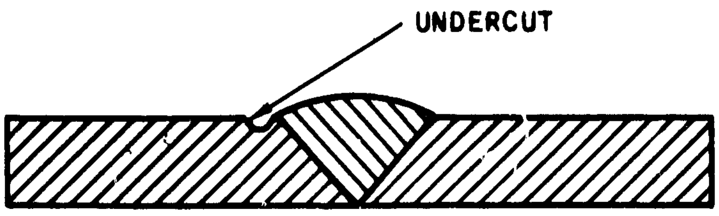
Lack of fusion occurs at the root of the weld? NO. We have discussed a discontinuity which does occur at the root of the weld <u>and</u> it does have the work "lack" in its name. But it is not lack of <u>fusion</u> which is a failure of the weld to fuse with the parent metal. Or it might be caused by a failure of the weld passes themselves to fuse. And this particular discontinuity occurs farther up in the weld than the root, correct?

Turn to page 7-43.

Correct! Lack of fusion occurs farther up in the weld than the root. It can be that the weld and base metal did not fuse or it might be that the weld passes themselves failed to fuse.

UNDERCUT

And the last discontinuity for our welding discussion is called UNDERCUT. Here is what if looks like.



UNDERCUT — this discontinuity occurs where the welder has melted and flushed out some of the parent metal in the line of fusion.

This is a discontinuity which would be most readily seen by visual inspection. It therefore is:

Subsurface . . . . Page 7-44

Open to the surface . . . . Page 7-45

From page 7-43

No, UNDERCUT is most readily seen by visual inspection. It would not be subsurface (beneath the surface) or it could not be inspected visually. It is, therefore, open to the surface.

Return to page 7-43 and take another look at the picture of an undercut and then turn to the page which the correct answer indicated.

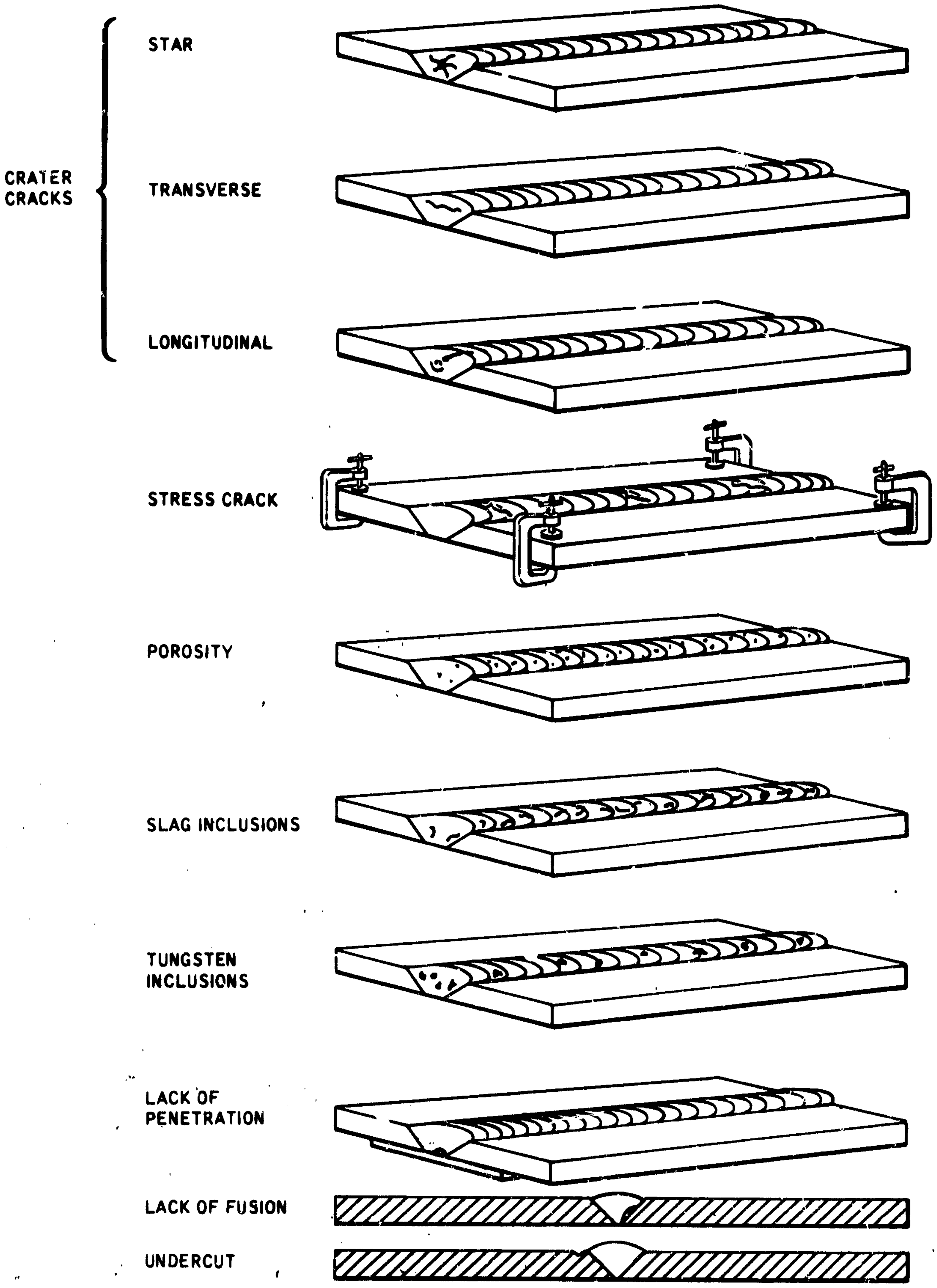
From page 7-43

Good, you realize if undercut can be inspected visually, then it has to be open to the surface. It isn't something which is hard to see. All that is necessary to inspect for undercut is to check the line of fusion — in other words, the meeting line of the weld and the parent metal. If there is undercut, some of the parent metal has been melted away.

Turn to the next page.

From page 7-45

Shown in order below are the weld discontinuities we have discussed.



Turn to the next page to review weld discontinuities.

From page 7-46

1. As in the other steel-working processes, welding can cause discontinuities within metal. The first we discussed were CRATER CRACKS. These are caused from improper use of the heat source and assume several shapes. One gets its name from its roughly s________ like shape.

5. beginning
end
between

6. Another crack which can occur in welds is due to the welded pieces being restrained. All welding builds up a certain amount of st____________ within the metal. In rigidly restrained parent metal this might relieve itself as a crack.

10. round (or nearly) round
inclusions

11. These ____________ inclusions have no definite direction and are a result of improper welding practices. Another improper welding technique — excessive welding current during tungsten - arc welding - causes a subsurface discontinuity termed tung__________ i__________.

15. parent

16. Lack of penetration and lack of fusion are due to improper welding practices as are most welding discontinuities. The final discontinuity discussed was caused by poor technique — cutting the parent metal. It is called under____________.

1. star

2. Star crater cracks are, of course, shaped roughly like a star. These can occur at the beginning or e______ of a weld or somewhere in between if a stop was made and the welder failed to fuse properly. Another type of crater crack is a t______verse crack.

6. stress

7. Cracks caused by stress usually occur across or t______________ to the weld. But since the heat affected zone is a temporarily weak area, s________ cracks could occur in the parent metal.

11. slag
tungsten inclusions

12. Because of the name which has been given these inclusions, you know that the electrode which causes them is made of ______________.

16. (under) cut

17. When the welder melts away the parent metal along the line of fusion, he is creating a discontinuity called u__________. This is visible to the eye and is therefore ____________ to the surface.

2. end trans (verse)

3. These transverse crater cracks go __________ the weld. They are the opposite of l____itudinal crater cracks which occur in the long direction of the weld.

7. transverse stress

8. These stress cracks which occur in the heat affected zone of the parent metal would probably extend in the same direction as the weld or ______gitudinal to the weld.

12. tungsten

13. Cracks and inclusions and porosity are among the several types of weld discontinuities. One type which can occur results when the weld fails to fuse properly with the parent metal at the root or with the backing. It is called l________ of penetration.

17. undercut open

18. There are three types of crater cracks. One is called a __________ crack because of its star shape. Another goes across or t________ to the weld. The third goes in the direction of the weld and is a l__________ crack.

3. across
long (itudinal)

4. T____________ crater cracks go across the weld and longitudinal cracks occur in the ____________ direction of the weld.

8. longitudinal

9. Cracks are not the only type of discontinuity which might be found in a weld. Another discontinuity, and one with which you should by now be familiar, is caused from entrapped gases. It is called p______________.

13. lack

14. Lack of p____________ occurs at the root or bottom of the weld. Another discontinuity also occurs because of a failure to fuse properly. It is found farther up than the root and is known as a lack of f_____________.

18. star
transverse
longitudinal

19. Two types of inclusions are (1) s_____ from failure to clean properly and (2) t_____. A l_____ of pen______ and a l_____ of f_____ means the metal is not completely fused. And, a visible discontinuity, a result of cutting away the parent metal, is u_____.

4. Transverse
long

5. Crater cracks — star, transverse, or longitudinal, — could occur in any one or all three places within a weld: the be__________, the e________ or somewhere in b__________.

Return to page 7-47, frame 6.

9. porosity

10. Yes, it is the r________(shape) or nearly r__________ subsurface porosity. This discontinuity might be joined by another if the welder fails to properly clean his weld of slag after each pass. It is known as slag in________________s.

Return to page 7-47, frame 11.

14. fusion

15. The discontinuity called lack of fusion occurs when the weld does not fuse with the p__________metal. Or possibly there is a failure of the passes themselves to fuse.

Return to page 7-47, frame 16.

19. slag, tungsten, lack of pentration, lack of fusion, undercut

Turn to page 52.

From page 7-51

You have just completed the programmed instruction course, Introduction to Non-destructive Testing.

Now you may want to evaluate your knowledge of the material presented in this handbook. A set of self-test questions are included at the back of the book. The answers can be found at the end of the test.

We want to emphasize that the test is for <u>your own</u> evaluation of <u>your</u> knowledge of the subject. If you elect to take the test, be honest with yourself - don't refer to the answers until you have finished. Then you will have a meaningful measure of your knowledge.

Since it is a self evaluation, there is no grade - no passing score. If you find that you have trouble in some part of the test, it is up to you to review the material until you are satisfied that you know it.

Now rotate the book 180° and flip to page T-1 at the back of the book.