NACA RM E56K30

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RESEARCH MEMORANDUM

SURVEY OF MICROSTRUCTURES AND MECHANICAL PROPERTIES OF OVER-TEMPERATURED S-816 TURBINE BUCKETS FROM J47 ENGINES

By S. Floreen and R. A. Signorelli

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
WASHINGTON
March 20, 1957

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SURVEY OF MICROSTRUCTURES AND MECHANICAL PROPERTIES OF OVER-TEMPERATURED S-816 TURBINE BUCKETS FROM J47 ENGINES

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SUMMARY

A group of buckets overtemperatured in service were given an extensive metallographic examination. Most of the buckets showed an overaged microstructure. Similar microstructures were also found in new buckets and in new buckets heated at 1500° F for 50 hours. Therefore, an overaged microstructure is not proof of overtemperature.

Several of the overtemperatured buckets had partially solutioned microstructures, which may be taken as evidence of overtemperature operation.

The stress-rupture lives of specimens obtained from overtemperatured buckets ranged from 66 to 216 hours when tested at conditions giving a 100-hour life for S-816 bar stock. The partially solutioned buckets had longer lives than the overaged buckets.

A considerable variation in hardness and microstructure was found in the new buckets. These variations are probably due to fabricating variables and could cause variation in bucket performance in service.

INTRODUCTION

An overtemperatured bucket is one that has been heated in service to a temperature greater than the allowable maximum operating temperature. In most engines in service today the bucket temperature is not measured, but the tailpipe temperature is measured. Studies have shown that when the tailpipe temperature reaches the operating limit of about 1275° to 1300° F in steady-state operation, a region in the buckets reaches a temperature of 1500° F. Hence, an overtemperatured bucket may be defined as one that has been heated in excess of 1500° F.

Overtemperature was sometimes observed by pilots but was usually noticed during engine overhaul by indirect evidence such as warped or cracked nozzle guide vanes. One practice has been to inspect the buckets and discard all those showing visible damage such as cracking, warping, or necking. Other buckets from the engine, however, often showed no visible damage. If overtemperature was suspected, four undamaged buckets were removed from the engine and examined microstructurally in order to determine whether they had been overtemperatured.

Heating S-816 above 1500° F is known to produce microstructural changes. Spheroidization and solution of carbides have been taken as evidence of overtemperature operation, and buckets showing these changes have been classified as overtemperatured. Similar changes in microstructure, however, might also take place during normal engine operation. Therefore, there is some question of whether or not microstructural examination can distinguish between overtemperature and nonovertemperature operation.

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This investigation evaluates the microstructural method of detecting overtemperature in S-816 buckets. A metallographic examination was made of new and overtemperatured buckets. New buckets were also heated and then microexamined to estimate the effect of normal operation. As a further check on the effects of overtemperature, stress-tupture tests were conducted on a group of the overtemperatured buckets.

PROCEDURE

Buckets Investigated

Eight new buckets and twenty buckets classified as overtemperatured were used for this investigation. Table I lists all the buckets and how they were investigated. The eight new buckets were selected at random from Air Force stock at the NACA Lewis laboratory.

The overtemperatured J47 buckets were furnished by the Air Force from their Oklahoma City Depot. Buckets 1 and 2 were from engine A, which exceeded a tailpipe temperature of 1832° F on acceleration. (Maximum tailpipe temperature is 1275° to 1300° F.) Buckets 3 and 4 were from engine B, which oversped 104 percent of rated speed with a tailpipe temperature greater than 1490° F. The remaining 16 buckets overtemperatured in service were of unspecified background.

Four of the buckets of unspecified overtemperature history were necked. A photograph showing an example of this necking is presented in figure 1. The necked buckets were 5, 6, 13, and 14 (table I).

Metallographic Survey

Buckets were sectioned for microexamination and hardness measurements as shown by the sketch in figure 2. All eight new buckets and twelve overtemperatured buckets including the four buckets from engines A and B, and two necked buckets were investigated by this method. In addition, small sections were cut from various parts of two of the new buckets and heated for 50 hours at 1500° F and then inspected metallographically.

Stress-Rupture Tests

Stress-rupture specimens were machined from eight overtemperatured buckets as shown by figure 3 and tested in stress rupture at a temperature of 1500° F and stress of 23,600 pounds per square inch. This temperature and stress would give a nominal 100-hour life for S-816 bar stock in the standard heat-treated condition. As shown in figure 3, a region adjacent to the stress-rupture specimen was photomicrographed in order to furnish a correlation of rupture life with microstructure.

RESULTS

Metallographic Survey

The microstructure of heat-treated S-816 is presented in figure 4(a). Aside from the residual columbium-tantalum-type carbides, the carbides that precipitate in aging are very fine. When subjected to increasingly higher temperatures, these fine carbides tend to coalesce and spheroidize, producing what is termed an overaged microstructure as illustrated in figure 4(b). At still higher temperatures, these carbides tend to redissolve into the matrix until the alloy becomes predominantly a solid solution with the exception of the very stable columbium-tantalum carbide precipitate.

The microstructures of the new buckets were in most cases typical of those found in heat-treated S-816 bar stock. Several regions were found, however, where the microstructure appeared slightly overaged, as shown in figures 5(a) to (e). A cold-worked region was also found in one of the new buckets (24) as shown in figure 5(f).

The microstructures found in the overtemperatured buckets are presented in figure 6. In general, the microstructure varied from the leading edge to the trailing edge of these buckets. The leading edge usually shows the greatest degree of overaging, as exemplified by the hyphenated or spheriodized structures found in this region, while the trailing edge shows much less overaging. The middle of the bucket

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generally shows very little overaging. The microstructure also varies somewhat from the hub to the tip of the buckets. That is, the leading edge at the hub is slightly different from the leading edge at the tip, and so on. In most cases, however, these variations are of much smaller magnitude than those from the leading edge to the trailing edge.

A considerable variation in microstructure was found between buckets 5 and 6, which were almost completely solutioned, and the remaining overtemperatured buckets. This solutioning indicates that the overtemperature must have been quite severe. Buckets 5 and 6 were necked which further indicates a severe overtemperature. All the remaining overtemperatured buckets investigated metallographically had overaged microstructures. The variations in this overaging may be shown by comparing buckets 12 and 4. Bucket 12 shows a large amount of carbide precipitation, while bucket 4 shows very little. The remaining buckets show more overaging than bucket 4, but less than 12. This moderately overaged microstructure might therefore be considered the typical microstructure of the overtemperatured buckets. A cold-worked region was also found in one of the overtemperatured buckets as indicated by the region at the trailing edge of bucket 3.

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The microstructures produced by heating sections of the new buckets for 50 hours at 1500° F are shown in figure 7. These specimens had moderately overaged microstructures quite similar to those found in most of the overtemperatured buckets.

The hardness data for all the buckets are presented in table II. There were few variations in hardness, but two of the new buckets, 22 and 23, each had a hardness range of Rockwell C-21 to 35. The remaining buckets had hardness values typical of S-816 bar stock, and no distinction could be made between the new and the overtemperatured buckets on the basis of hardness values.

Stress-Rupture Tests

The results of the stress-rupture tests are presented in table III. The rupture life of the overtemperatured buckets ranged from 66 to approximately 216 hours with an average life of 133 hours.

The microstructures of the specimens before testing are shown in figure 8 in order of increasing rupture life. The specimens moderately overaged had shorter rupture lives than those partially solutioned.

DISCUSSION OF RESULTS

The results showed that an overaged microstructure similar to those found in the overtemperatured buckets can be produced by heating sections

from new buckets at 1500° F for 50 hours. This temperature roughly corresponds to full-power operation for the engine and is not an overtemperature. It seems very likely, therefore, that buckets that had been run at normal operating temperatures may appear overtemperatured. Furthermore, overaged structures were also found in some regions in the new buckets.

An overaged microstructure, therefore, is not positive evidence of overtemperature operation. Only when partial solutioning occurs does overtemperature produce a unique microstructure. The partially solutioned buckets examined, however, would have been discarded during inspection because they showed visible necking. Partial solutioning might occur with a high temperature and low stress, such as during a hot start, with no visible damage to the bucket. In this instance, microexamination would detect overtemperature.

The survey of the overtemperatured buckets showed that the leading edge of these buckets was usually overaged while the midchord was not. Hence, it might be thought that overtemperature could be detected by variation in microstructure of a bucket. This detection might be possible if overtemperature always involved a high temperature for a short time and if all the buckets had uniform microstructures when new. Such is not the case, however. Overtemperature could occur with a wide variety of time-temperature conditions, and the new buckets did not have uniform microstructures. Hence, it does not appear likely, particularly with the present variation in microstructure of new buckets, that overtemperature can be reliably detected by a variation in microstructure between the leading edge and the midchord of a bucket.

As far as rupture life is concerned, the moderately overtemperatured buckets (overaged) ranged in life from 66 to 216 hours, which is within the scatterband of rupture life for S-816 bar stock. Hence, it is difficult to estimate the effect of overtemperature on the strength for these buckets. The partially solutioned buckets, however, had longer rupture lives (212 and 216 hr) than the overaged buckets (fig. 8).

One of the significant results of this investigation was the variations in microstructure and hardness of the new buckets. Several of these buckets showed signs of overaging, while others had a cold-worked region. Two buckets each had hardness values ranging from Rockwell C-21 to 35. In view of such variations, it would appear that scatter in bucket performance may be partially due to fabricating variables. Certainly, if there were less variation, a more uniform performance in service might be expected. Therefore, the problem of fabricating variables and how to control them seems worthy of more study.

SUMMARY OF RESULTS

Twelve buckets overtemperatured in service were inspected metallographically. In addition, eight overtemperatured buckets were tested in stress rupture. Eight new buckets were also examined metallographically in the as-received condition and after heating at 1500° F for 50 hours. The following results were obtained:

1. An overaged microstructure is not definite proof of overtemperature since similar microstructures were found in both new buckets and those heated at 1500° F. Partial solutioning, however, may be taken as evidence of overtemperature.

2. The rupture lives of the overtemperatured buckets ranged from 66 to 216 hours when tested at conditions giving a nominal 100-hour life for S-816 bar stock. Partially solutioned specimens had longer lives than overaged ones.

3. Signs of overaging and cold work were found in some of the new buckets. Hardness ranging in a single bucket from Rockwell C-21 to 35 was also found in two of the eight new buckets examined. These variations, probably due to fabricating variables, could cause scatter in bucket performance in service.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, December 5, 1956

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TABLE I. - BUCKETS INSPECTED

Bucket	Manufacturer	Condition	Examination
1	A	Overtemperature; engine A	Micro survey
2	A	Overtemperature; engine A	
3	B	Overtemperature; engine B	
4	C	Overtemperature; engine B	
5	D	Overtemperature; necked	
6	C		
7	A	Overtemperature; unspecified history	
8	A		
9	E		
10	A		
11	F		
12	A		
13	B	Overtemperature; necked	Stress rupture
14	D		
15	B	Overtemperature; unspecified history	
16	E		
17	F		
18	F		
19	A		
20	F		
21	A	New	Micro survey + heat treatment (1500° F for 50 hr)
22	A		
23	A		
24	A		
25	B		
26	B		
27	A		
28	F		

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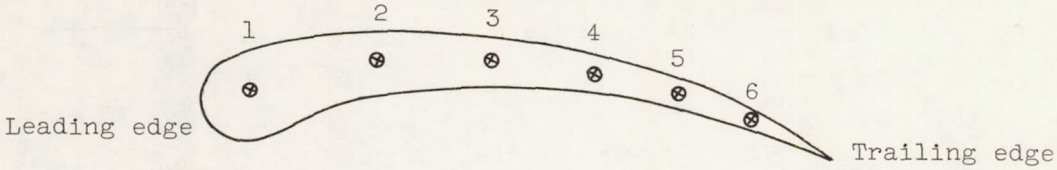
TABLE II. - ROCKWELL C HARDNESS VALUES FOUND IN BUCKETS



Bucket		1	2	3	4	5	6
1	Tip	29	27	27	27	28	23
	Mean	30	29	28	27	27	24
	Hub	27	28	28	27	27	24
2	Tip	25	25	26	28	30	31
	Mean	25	25	25	26	27	28
	Hub	25	24	24	25	26	27
3	Tip	28	29	30	31	33	35
	Mean	31	29	29	30	33	35
	Hub	32	30	30	29	31	33
4	Tip	27	26	25	26	25	22
	Mean	25	25	25	25	25	25
	Hub	26	27	26	27	27	27
5	Tip	30	30	29	29	29	25
	Near tip	22	24	24	24	24	23
	Mean	23	24	24	24	25	23
	Hub	27	27	26	27	27	28
6	Tip	27	28	27	27	26	25
	Near tip	23	24	24	23	22	21
	Mean	23	24	25	25	25	23
	Hub	26	27	28	28	27	27
7	Tip	25	25	24	25	24	21
	Mean	26	25	26	24	24	25
	Hub	25	27	27	25	27	27
8	Tip	30	27	26	26	27	23
	Mean	30	28	27	27	28	27
	Hub	28	27	27	27	28	27
9	Tip	27	27	28	28	27	32
	Mean	30	27	27	28	29	33
	Hub	30	28	27	28	30	33
10	Tip	25	26	25	25	25	25
	Mean	27	28	27	27	27	29
	Hub	27	27	27	28	28	27
11	Tip	31	29	26	25	28	29
	Mean	33	27	26	27	28	28
	Hub	31	27	27	26	27	27

Bucket		1	2	3	4	5	6
12	Tip	27	26	26	28	31	31
	Mean	27	27	26	26	27	28
	Hub	27	26	25	26	26	26
21	Tip	27	28	28	29	28	24
	Mean	28	27	26	25	26	25
	Hub	27	27	27	27	28	29
22	Tip	29	28	26	28	30	30
	Mean	30	27	25	24	27	35
	Hub	24	24	23	21	25	27
23	Tip	25	27	29	27	25	23
	Mean	21	23	23	26	29	35
	Hub	24	21	23	24	25	26
24	Tip	30	29	27	27	25	24
	Mean	27	28	29	28	28	27
	Hub	27	28	29	28	27	26
25	Tip	27	28	29	28	27	25
	Mean	27	25	24	25	25	26
	Hub	29	28	27	28	31	34
26	Tip	24	25	27	28	28	28
	Mean	24	24	23	25	27	27
	Hub	24	23	23	25	27	29
27	Tip	23	24	25	26	25	26
	Mean	26	25	26	26	26	30
	Hub	24	24	23	24	25	25
28	Tip	28	28	29	30	30	29
	Mean	29	30	30	30	29	27
	Hub	30	30	30	29	30	30

Hardnesses from region cut next to stress-rupture specimen

13	24	25
14	24	24
15	28	28
16	25	26
17	28	29
18	29	29
19	25	26
20	31	31

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TABLE III. - RUPTURE LIVES OF OVERTEMPERATURED BUCKETS

[All specimens tested at 1500° F and 23,600 psi.]

Bucket	Rupture life, hr
13	216.2
14	211.5
15	84.9
16	66
17	68.7
18	200.5
19	68.6
20	152.7
Av., 133.3	

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Figure 1. - Necked bucket.

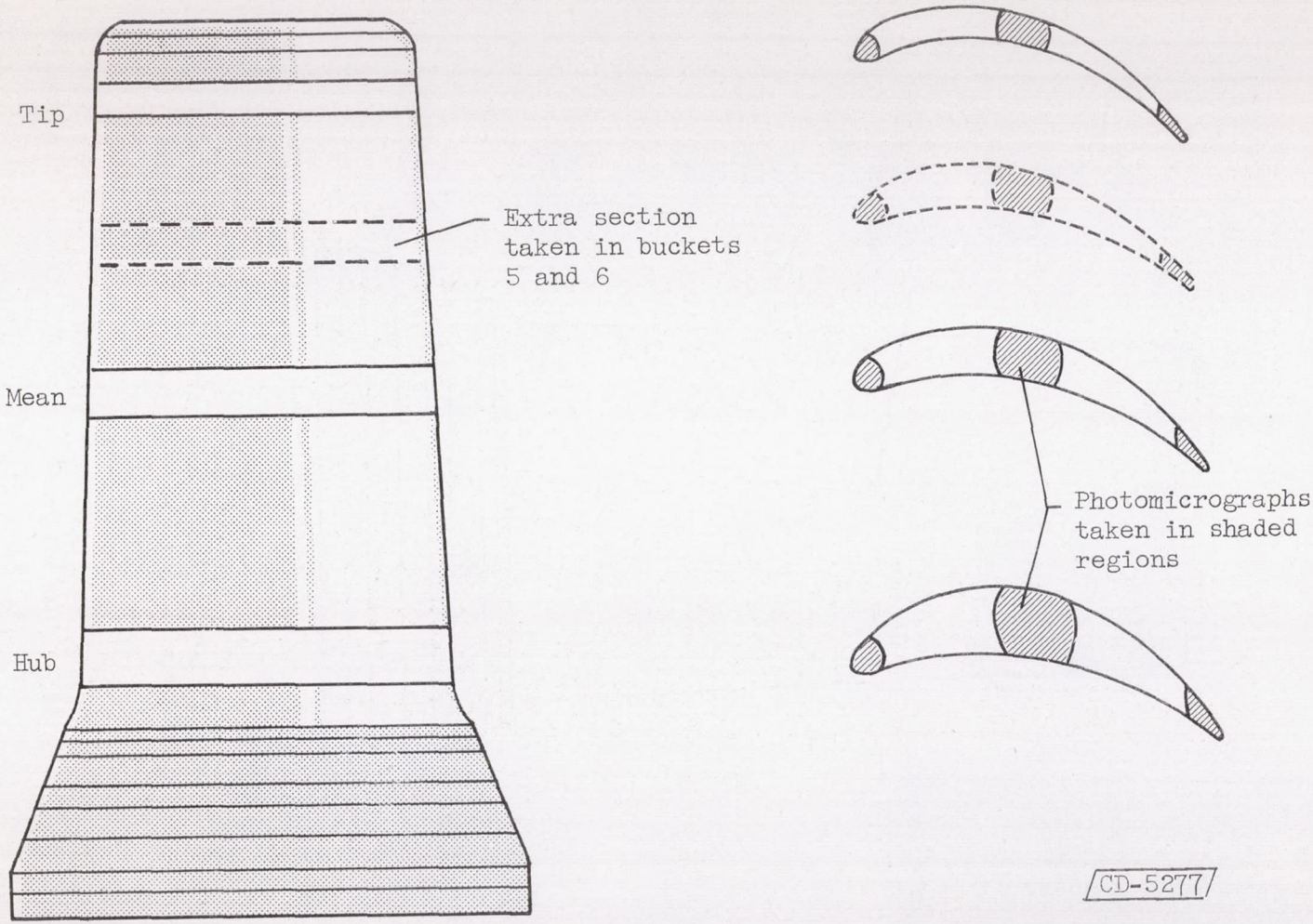

Figure 2. - Sketch showing how buckets were sectioned and inspected.

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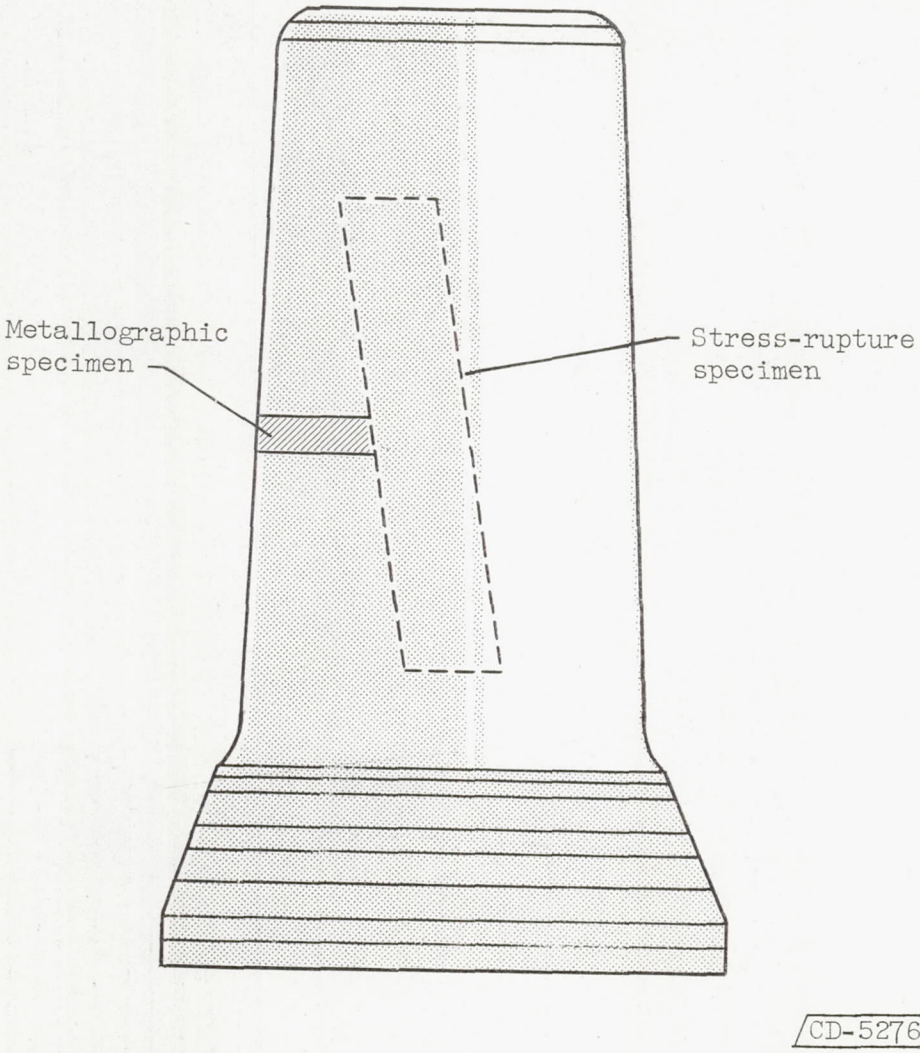

Figure 3. - Sketch showing how stress-rupture specimen and metallographic specimen were cut from buckets.

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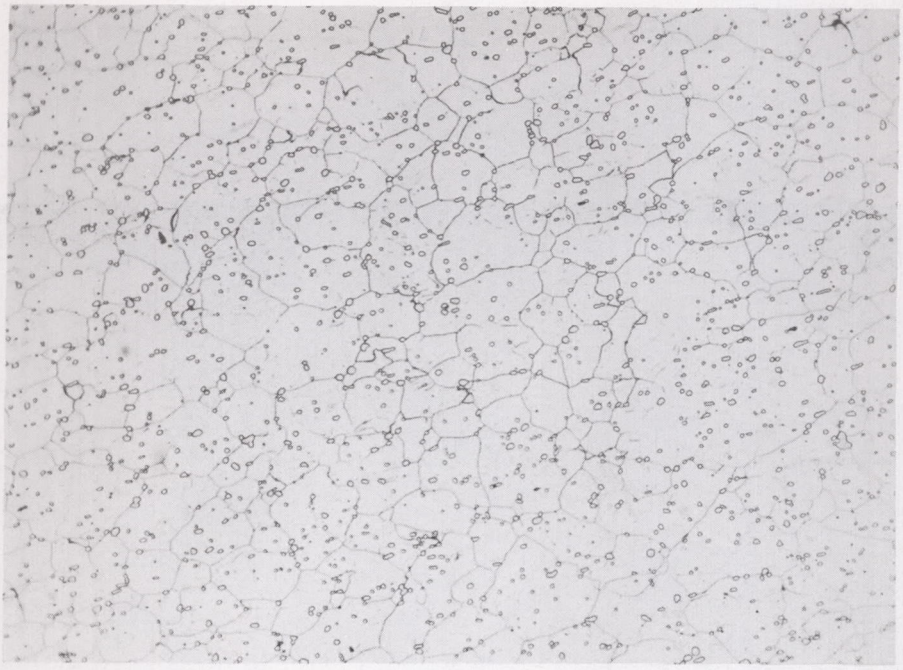
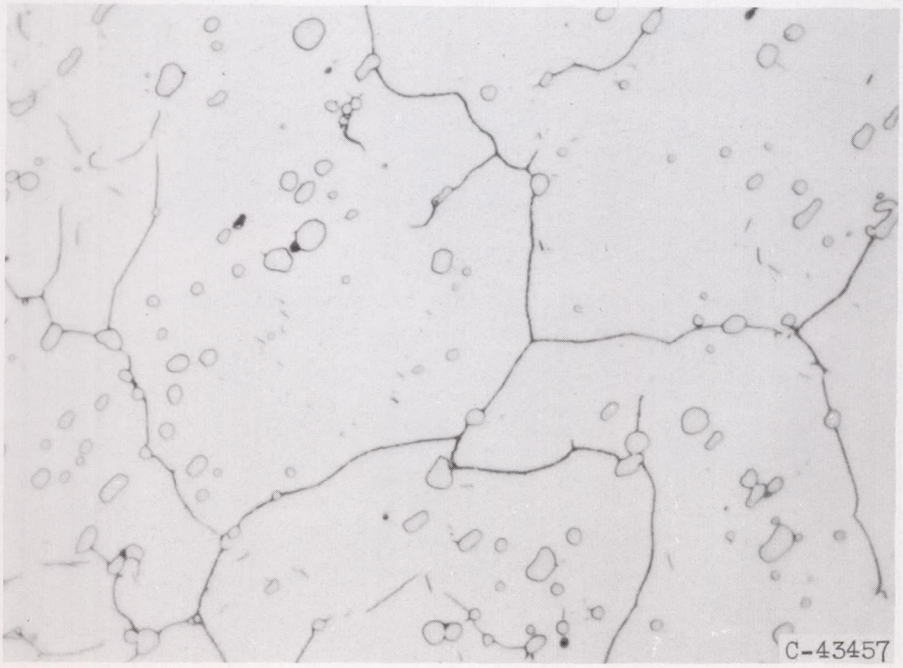


X250.



X1000.

(a) Normal. Reduced 6 percent in printing.

Figure 4. - Microstructure of S-816.

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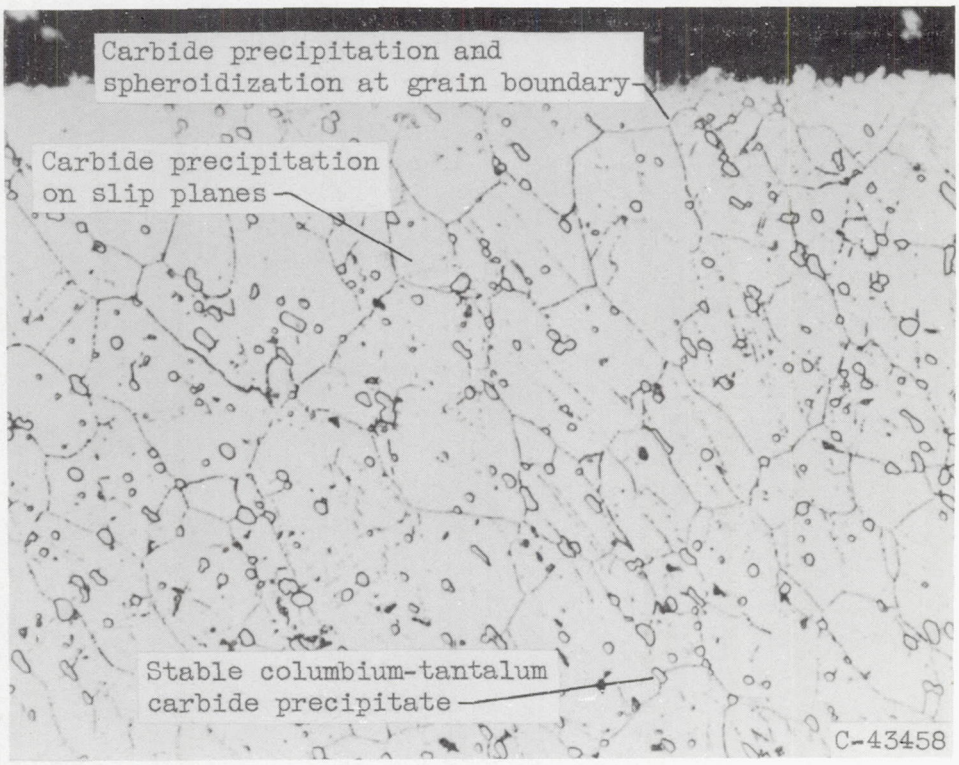

(b) Overaged. X750.

Figure 4. - Concluded. Microstructure of S-816.

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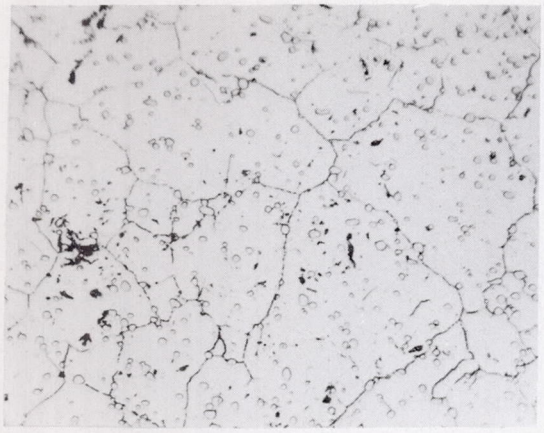
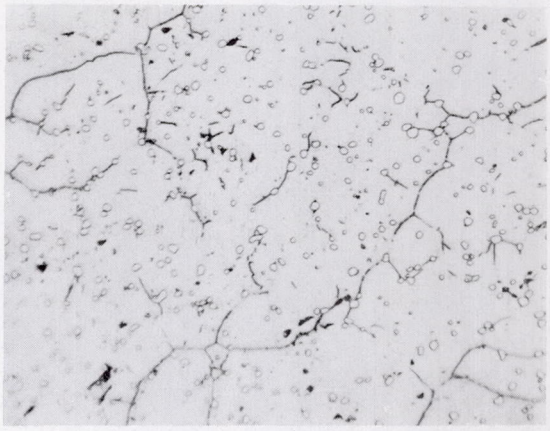
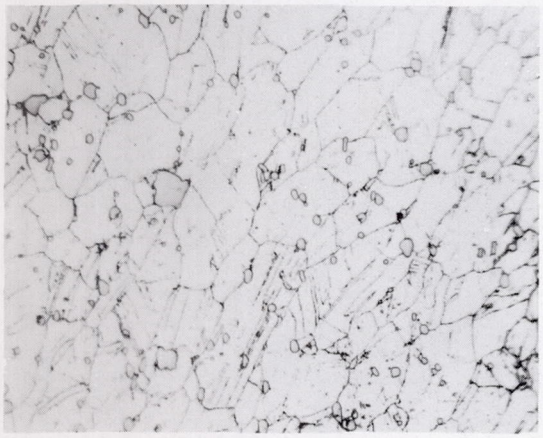


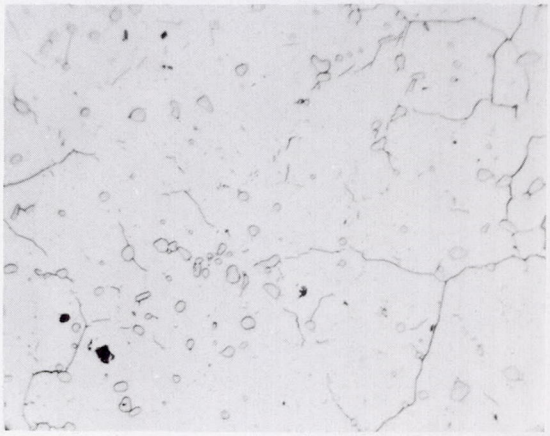
(a) Bucket 21, mean middle.



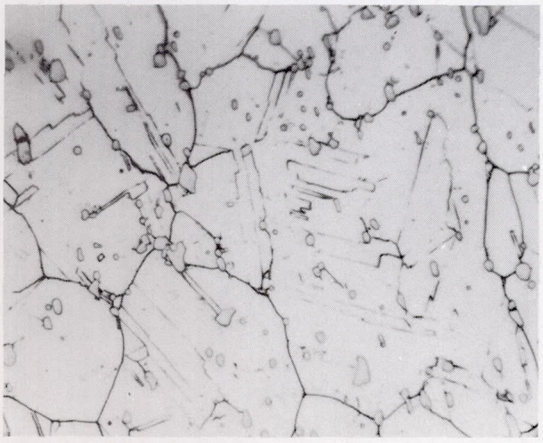
(b) Bucket 21, hub trailing edge.



(c) Bucket 22, mean trailing edge.



(d) Bucket 24, tip leading edge.

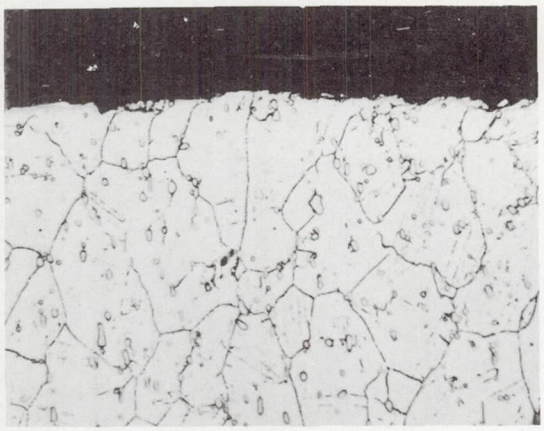


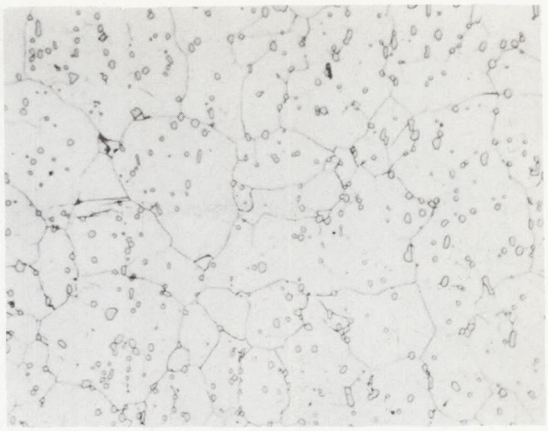
(e) Bucket 25, hub trailing edge.

(f) Bucket 24, hub trailing edge.

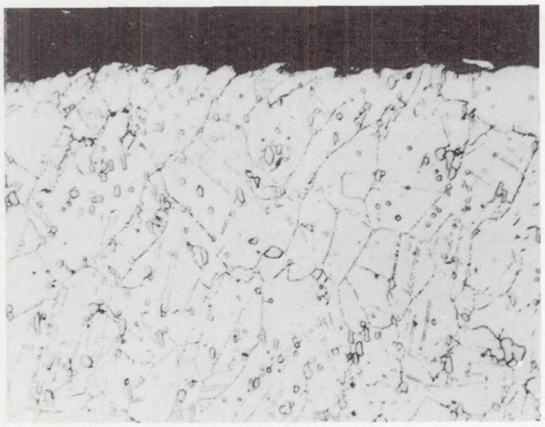
Figure 5. - Microstructures found in some new buckets. Reduced 44 percent in printing. X750.

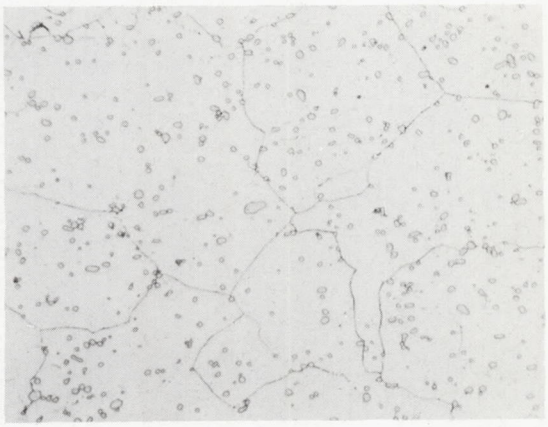
Tip



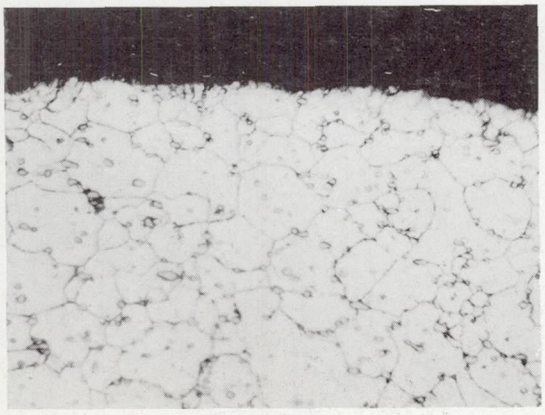


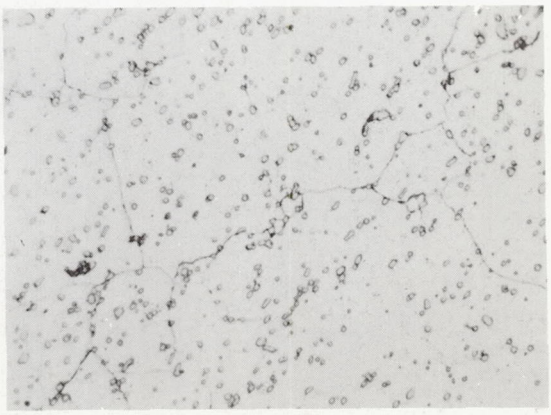
Mean





Hub





Leading edge

Middle

(a) Bucket 1. Reduced

Figure 6. - Microstructures
Etch, aqua regia plus

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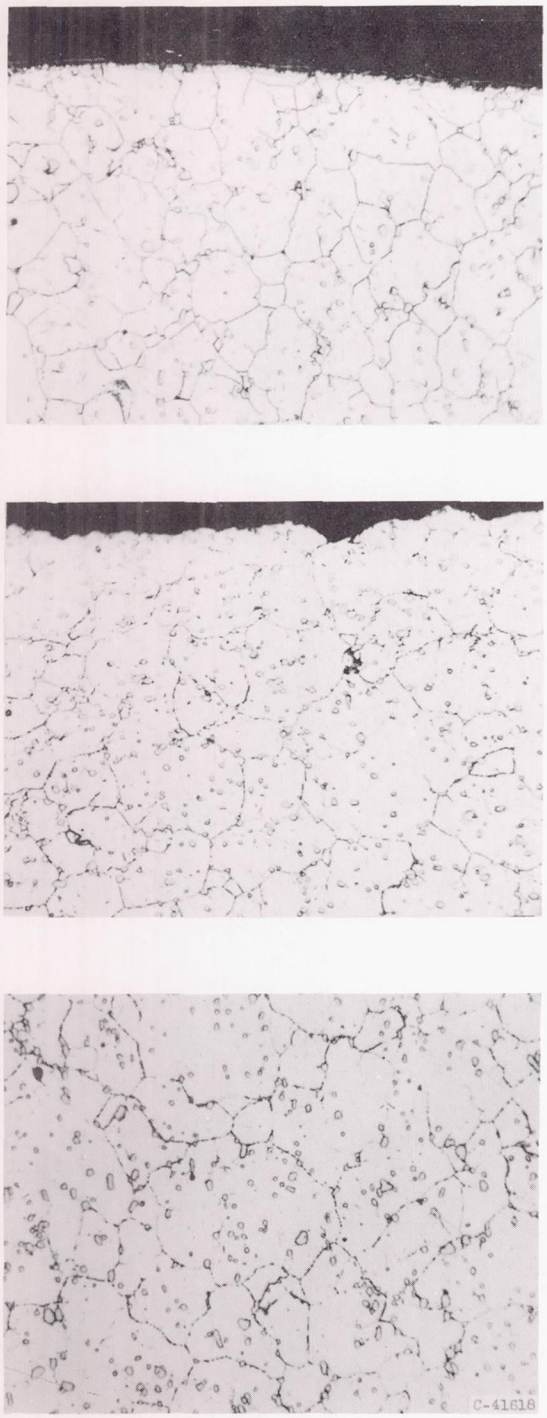

Trailing edge

44 percent in printing.

of overtemperatured buckets.
glycerine. X750.

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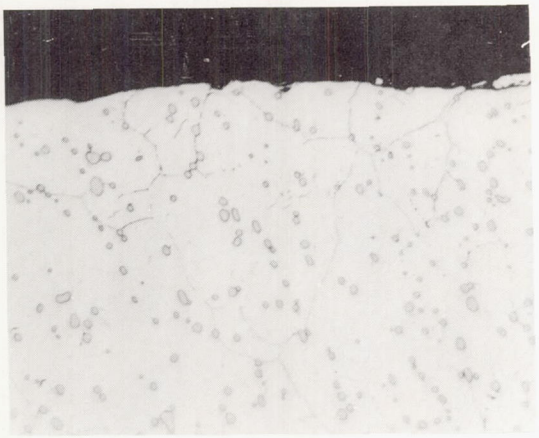
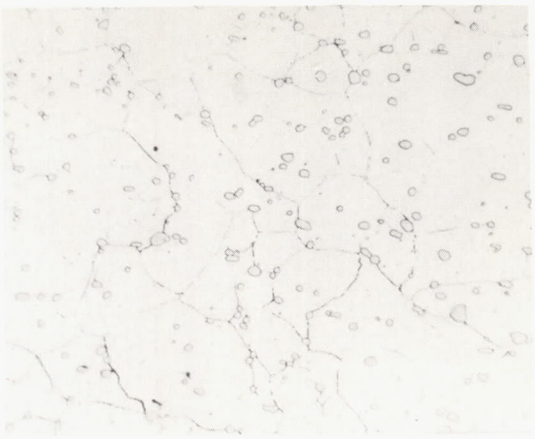
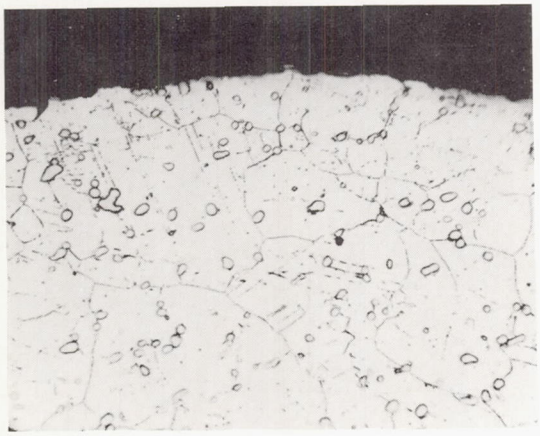
Tip

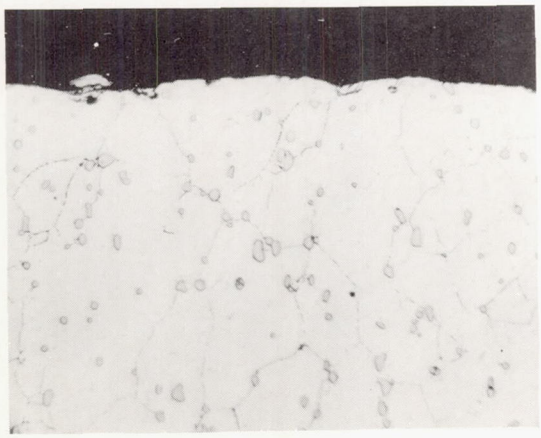


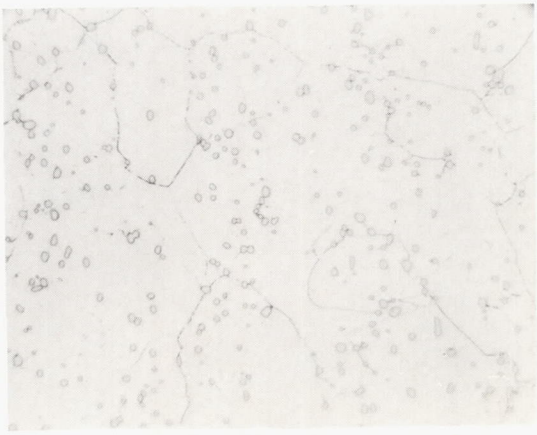


Mean



Hub





Leading edge

Middle

(b) Bucket 2. Reduced

Figure 6. - Continued. Microstructures Etch, aqua regia plus glycerine.

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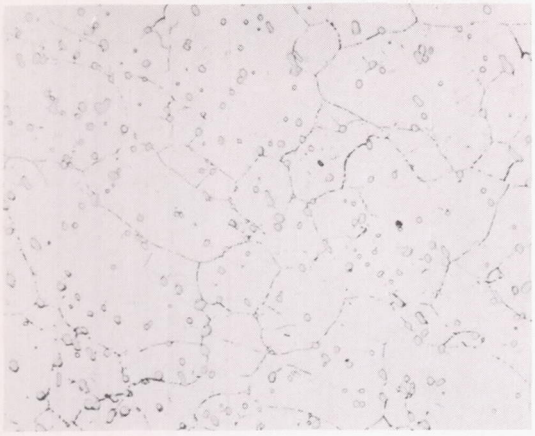
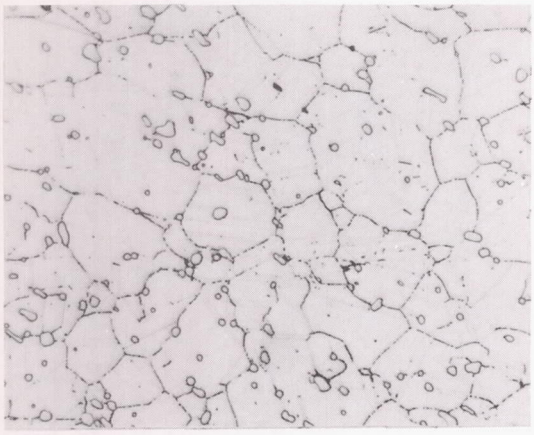
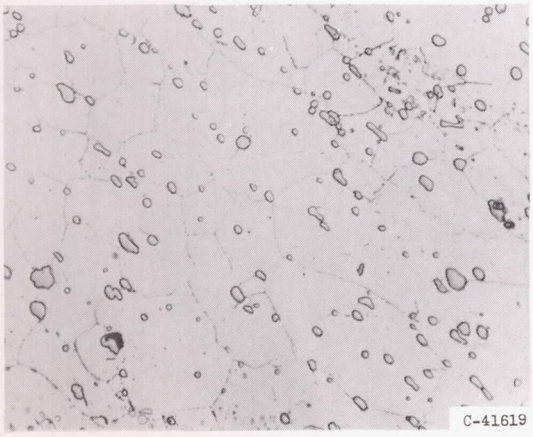
CR-3 back







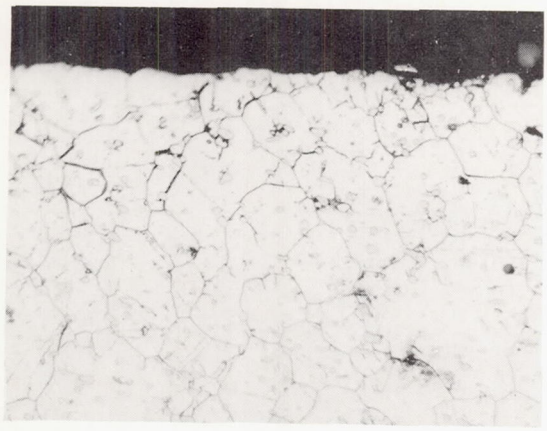
Trailing edge

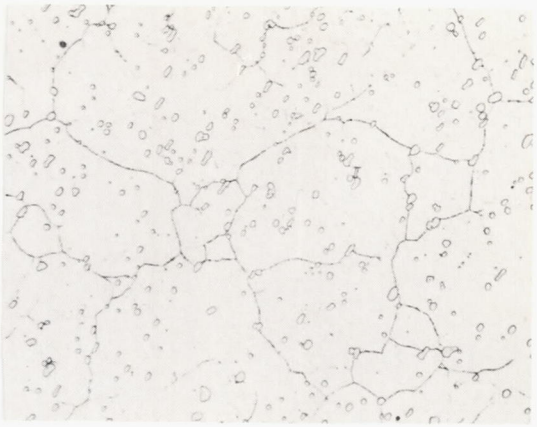
44 percent in printing.

of overtemperatured buckets.
X750.

4086

Tip





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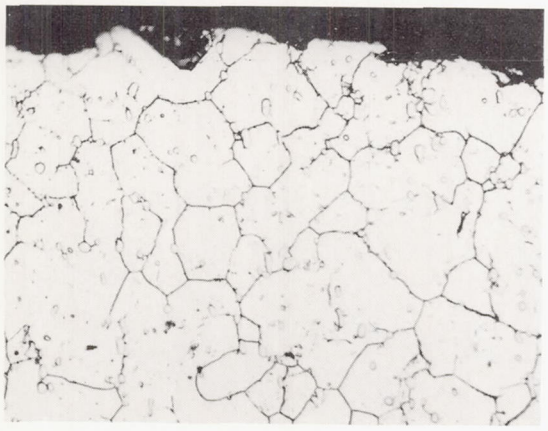
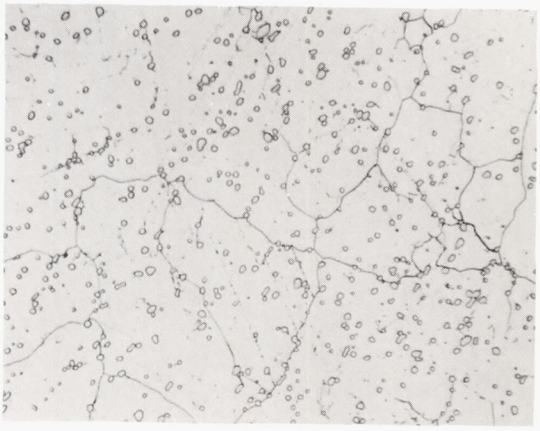
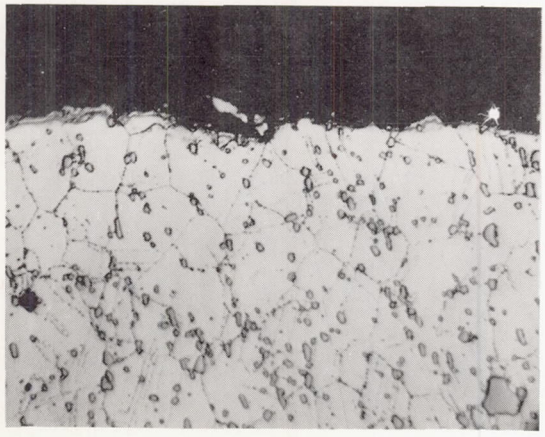
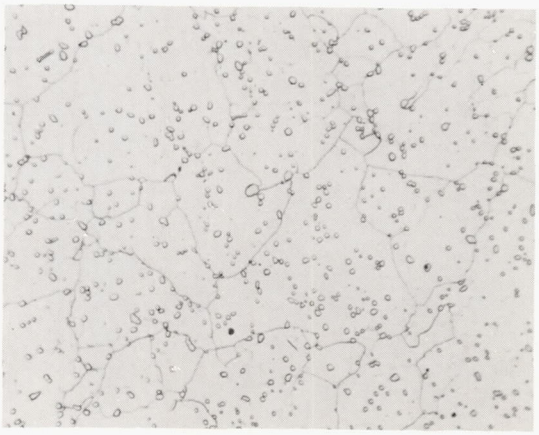




Hub





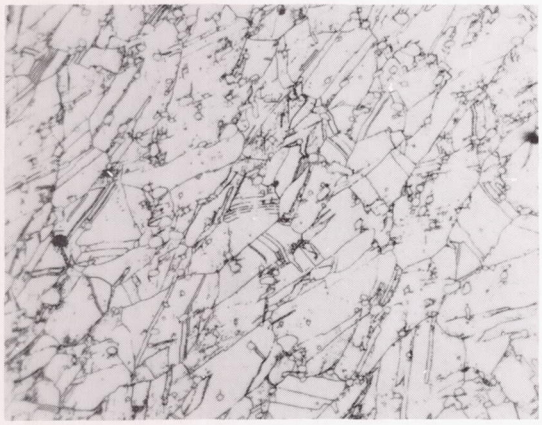
Leading edge

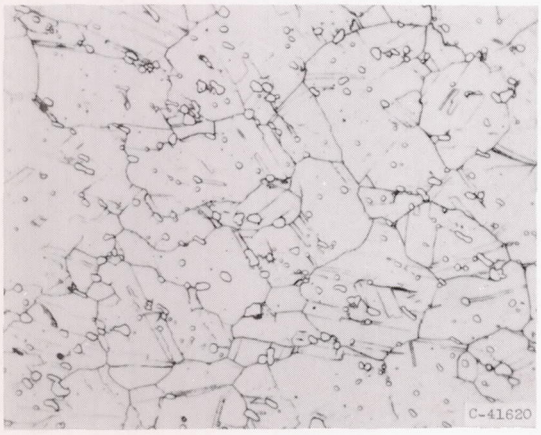
Middle

(c) Bucket 3. Reduced

Figure 6. - Continued. Microstructures
Etch, aqua regia plus glycerine.

4086





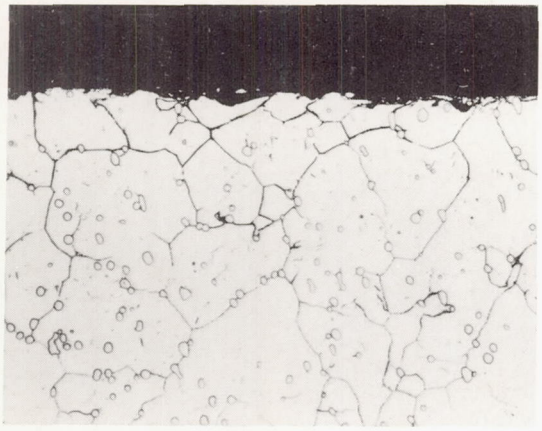
Trailing edge

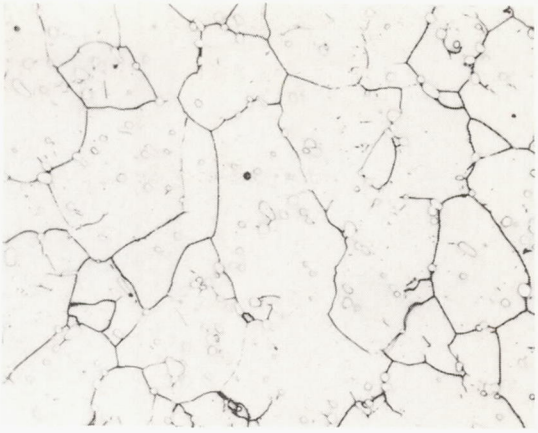
44 percent in printing.

of overtemperatured buckets.
X750.

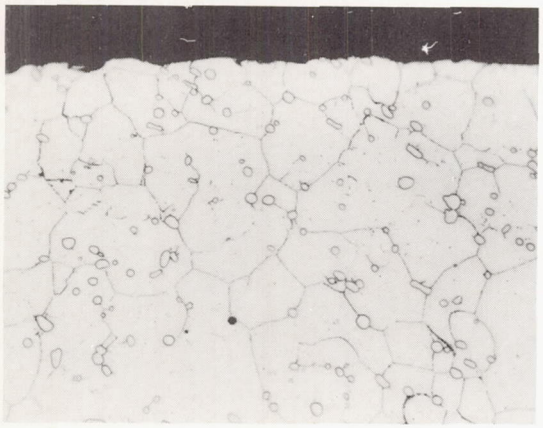
4086

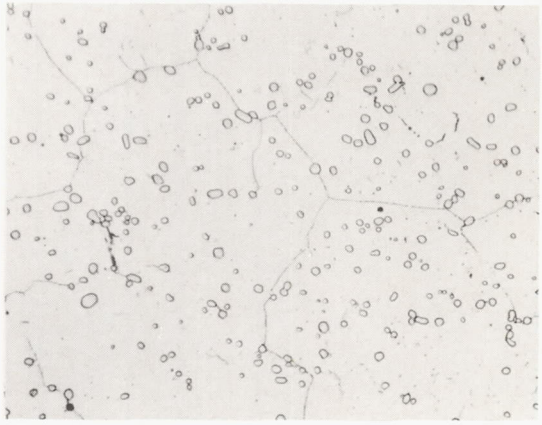
Tip



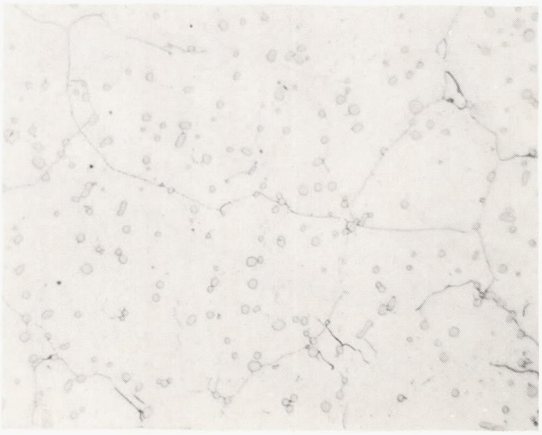


Mean





Hub



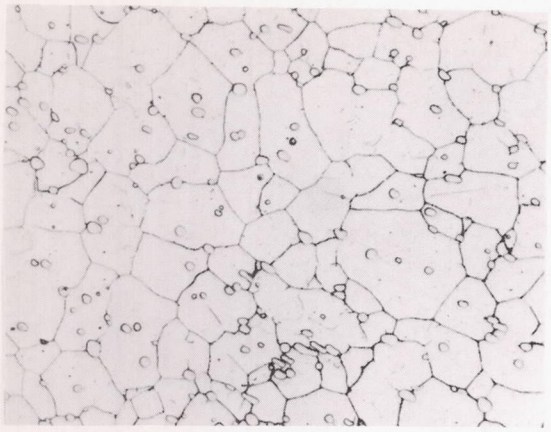
Leading edge

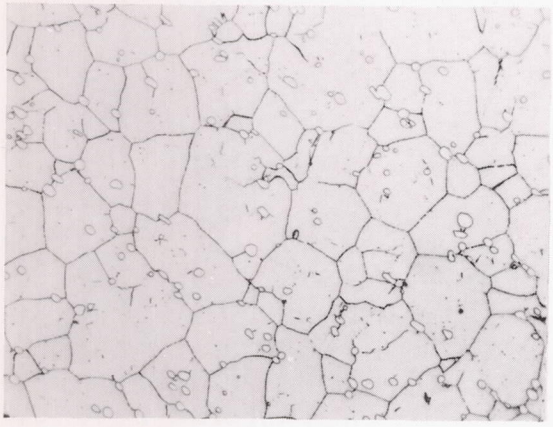
Middle

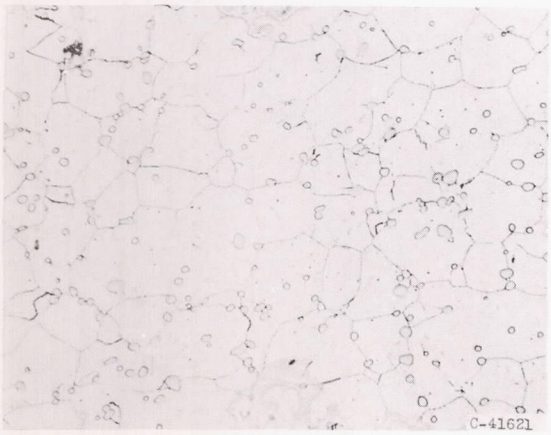
(d) Bucket 4. Reduced

Figure 6. - Continued. Microstructures
Etch, aqua regia plus glycerine.

4086





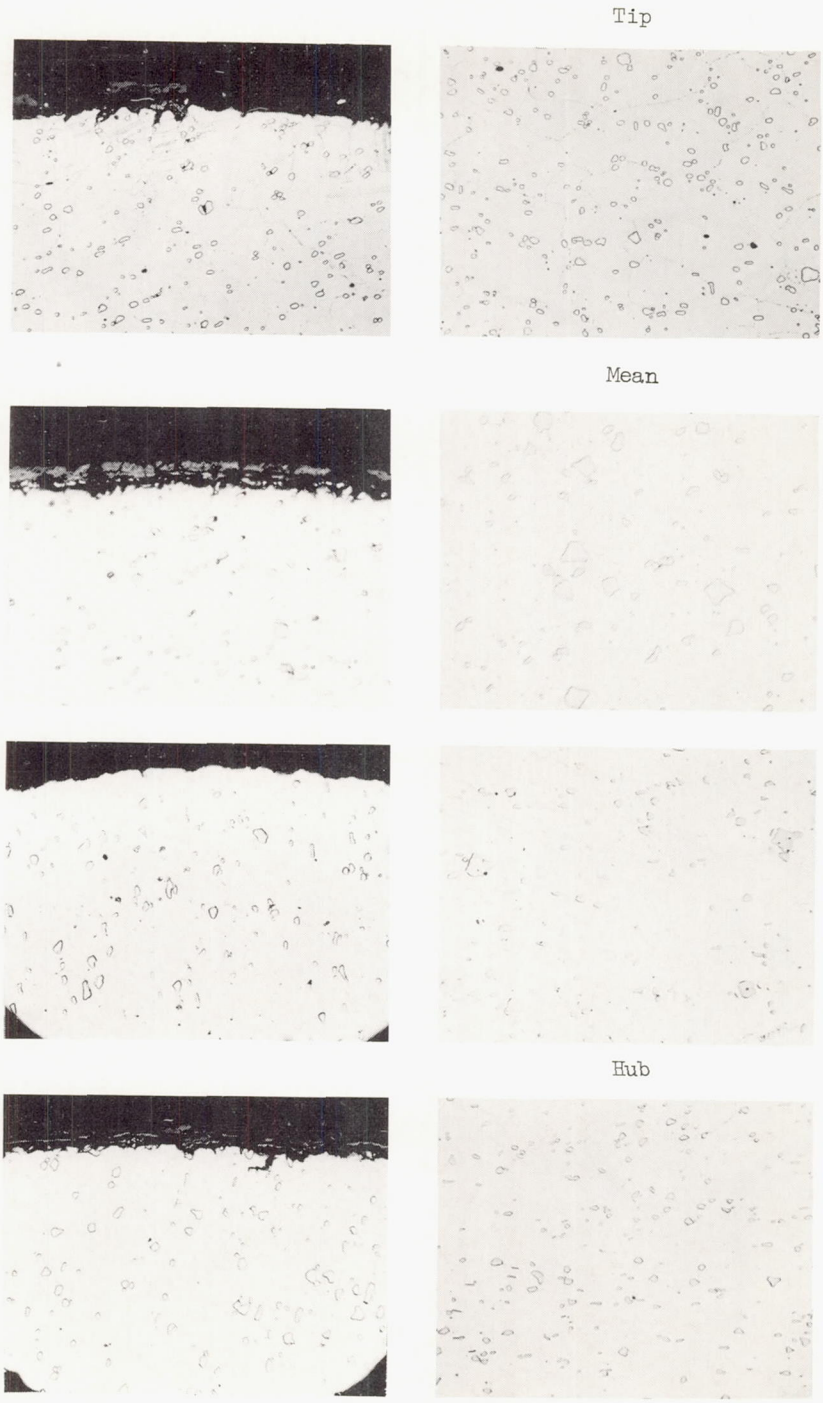


Trailing edge

44 percent in printing.

of overtemperatured buckets.
X750.

4086

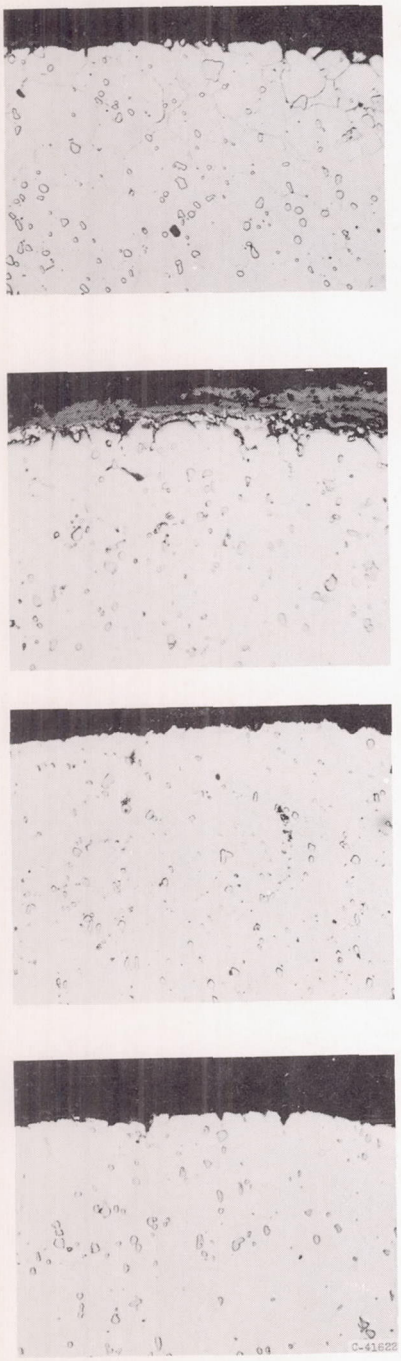


(e) Bucket 5. Reduced

Figure 6. - Continued. Microstructures
Etch, aqua regia plus glycerine.

4086

CR-4



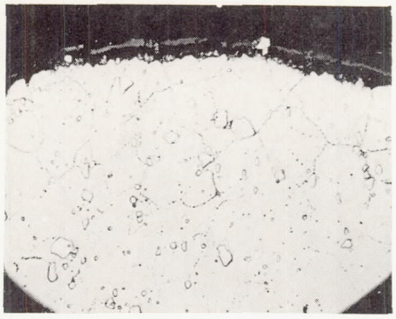
Trailing edge

59 percent in printing.

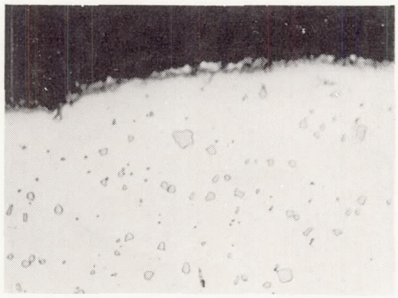
of overtemperatured buckets.
X750.

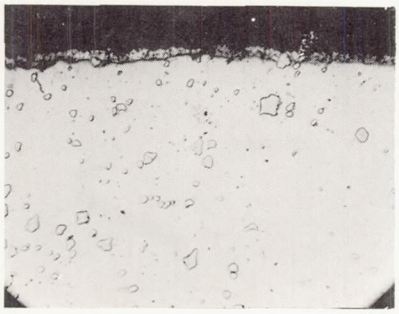
4086

Tip



Mean





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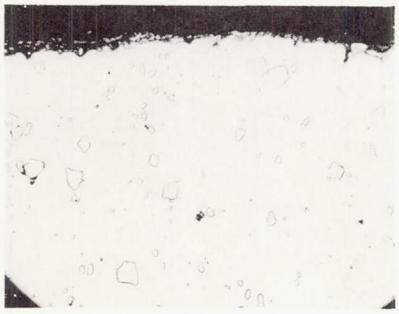
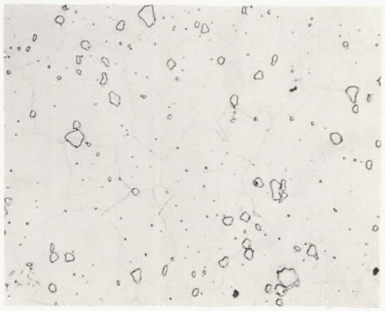




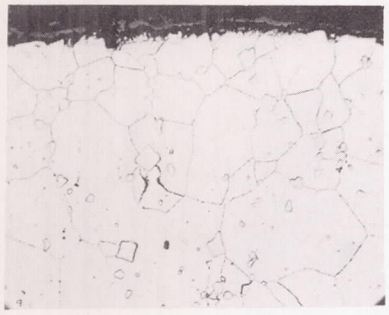
Leading edge Middle

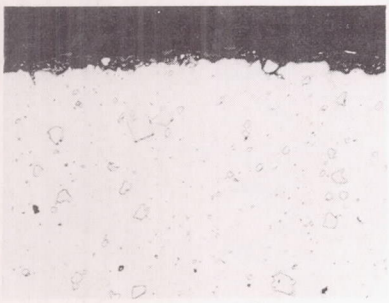
(f) Bucket 6. Reduced

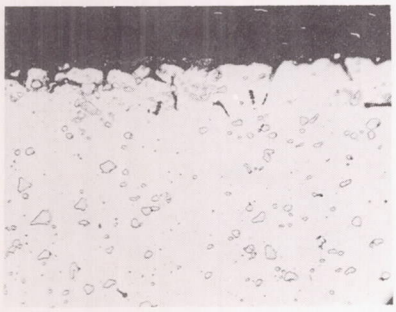
Figure 6. - Continued. Microstructures
Etch, aqua regia plus glycerine.

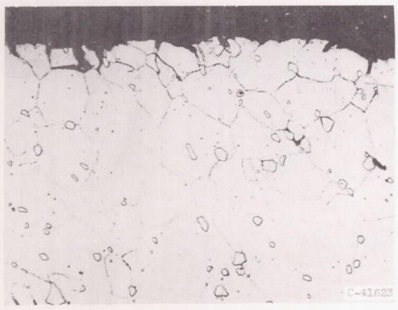
4086

CR-4 back









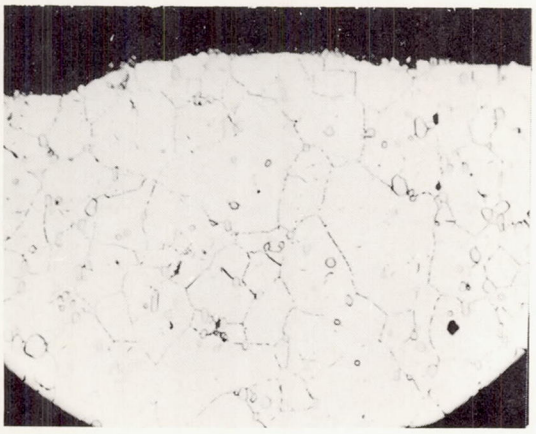
Trailing edge

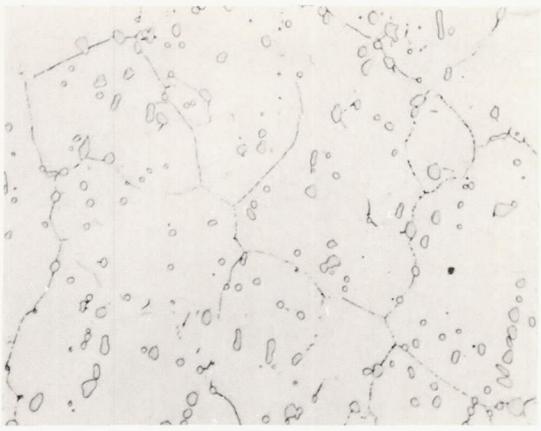
59 percent in printing.

of overtemperatured buckets.
X750.

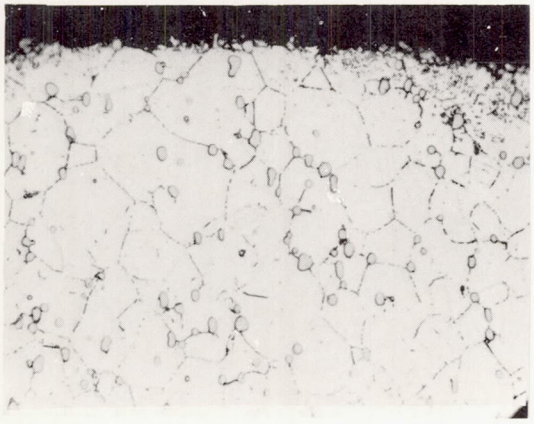
4086

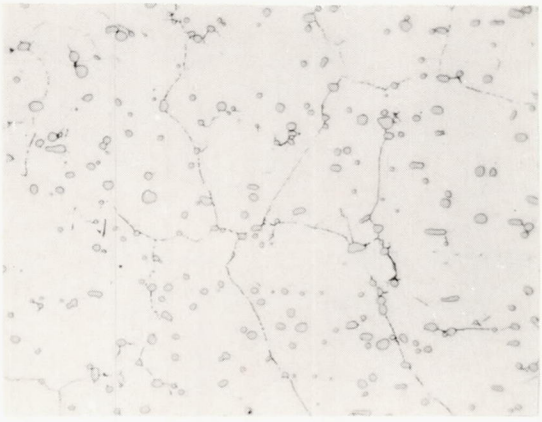
Tip



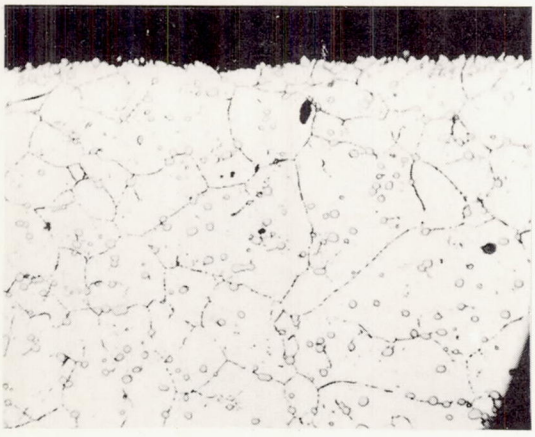


Mean

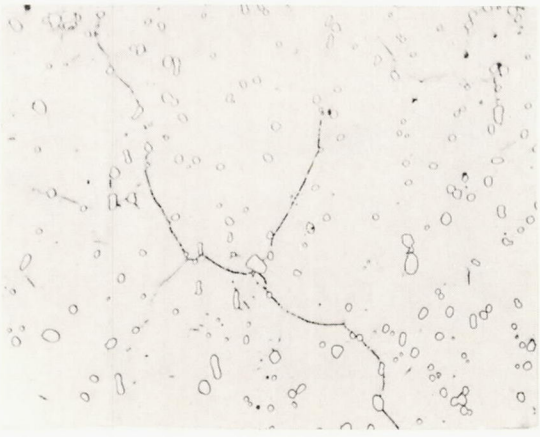




Hub



Leading edge

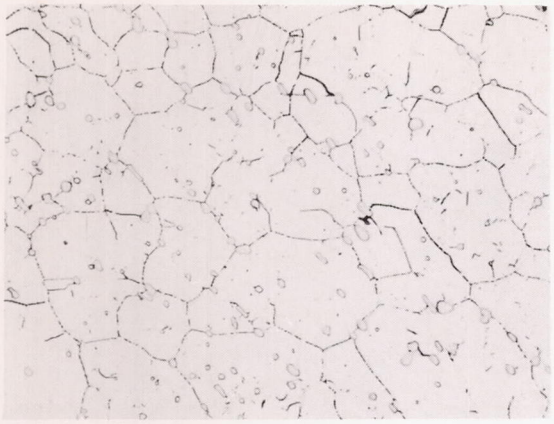


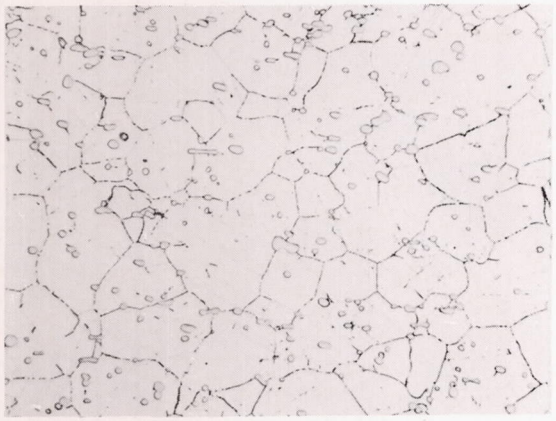
Middle

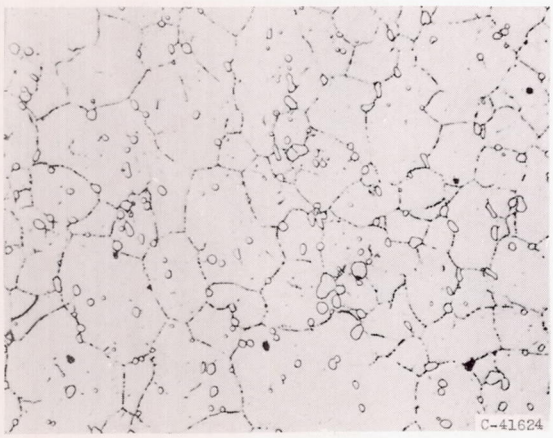
(g) Bucket 7. Reduced

Figure 6. - Continued. Microstructures
Etch, aqua regia plus glycerine.

4086



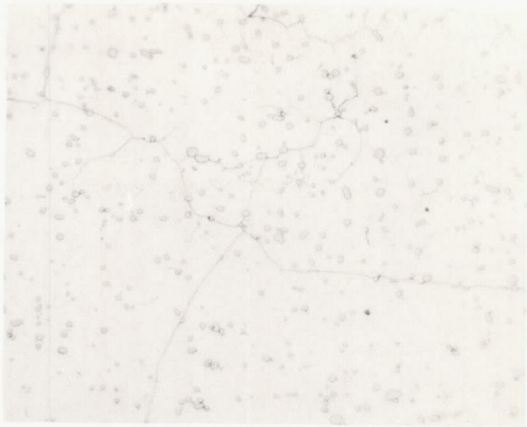




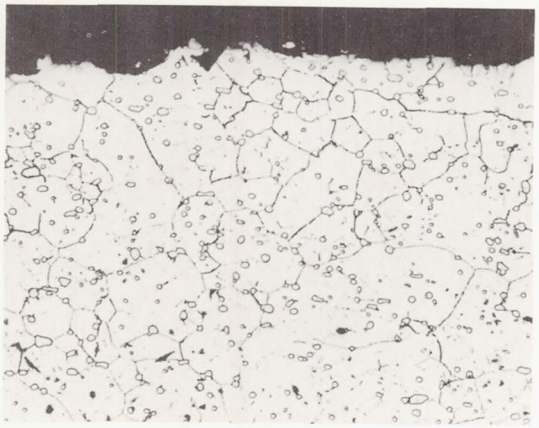
Trailing edge

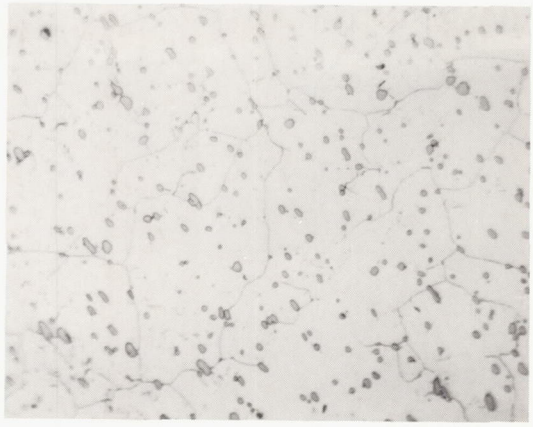
44 percent in printing.

of overtemperatured buckets.
X750.



Mean





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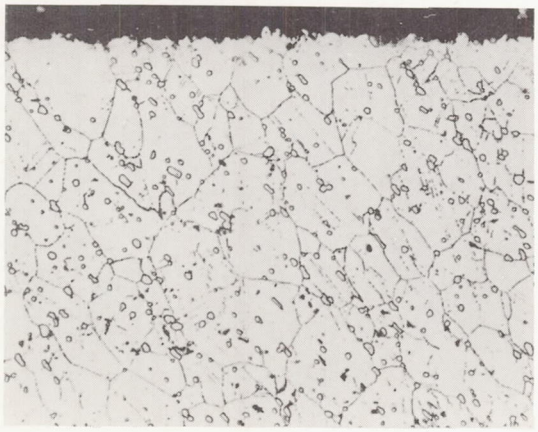


Leading edge

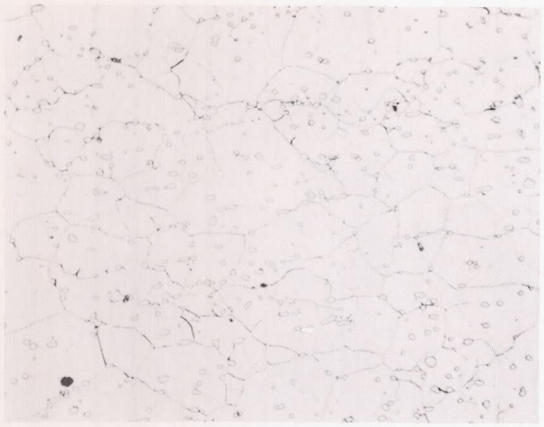
Middle

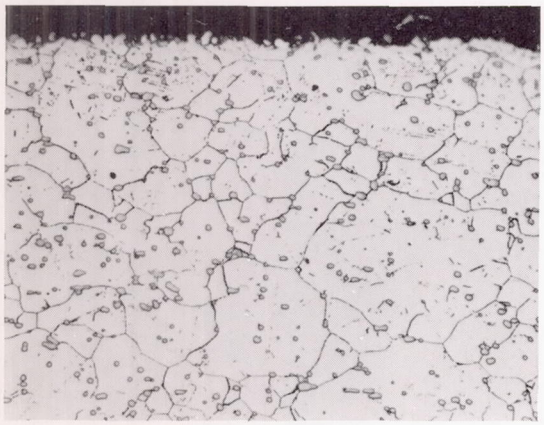
(h) Bucket 8. Reduced

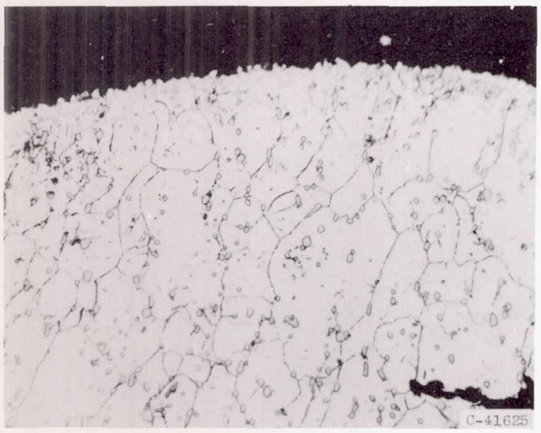
Figure 6. - Continued. Microstructures
Etch, aqua regia plus glycerine.

4085

4086





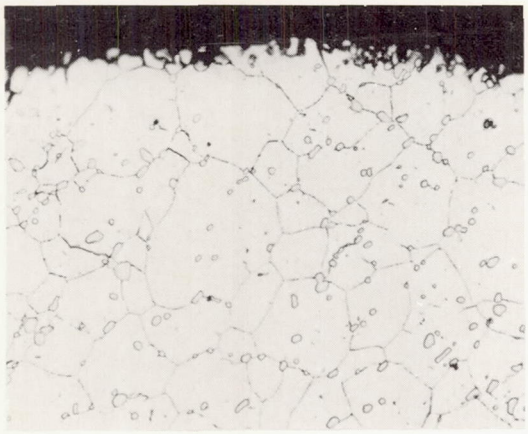


Trailing edge

44 percent in printing.

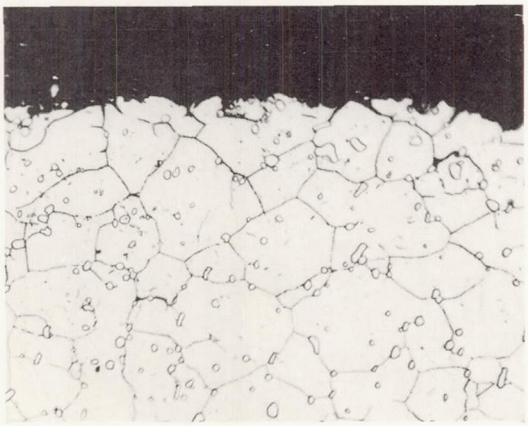
of overtemperatured buckets.
X750.

Tip



Mean

Hub



Leading edge

Middle

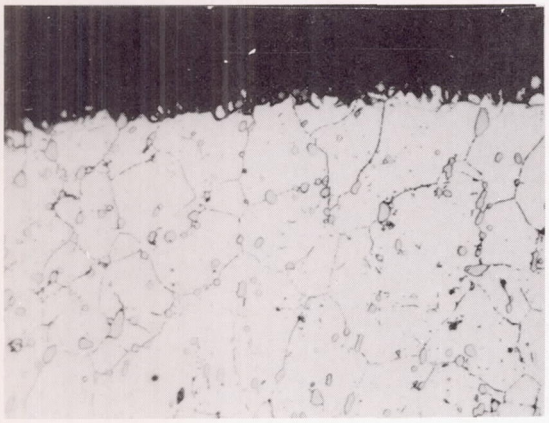
(i) Bucket 9. Reduced

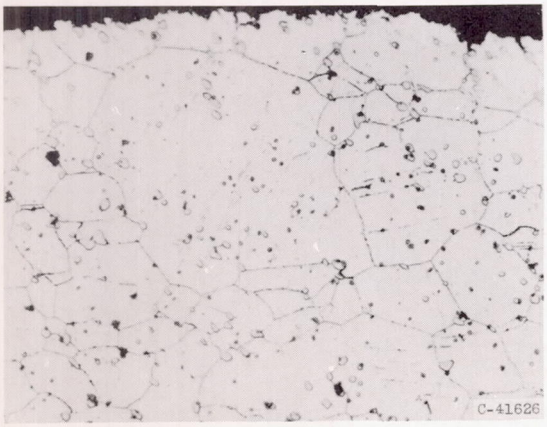
Figure 6. - Continued. Microstructures
Etch, aqua regia plus glycerine.

4085

4086

CR-5





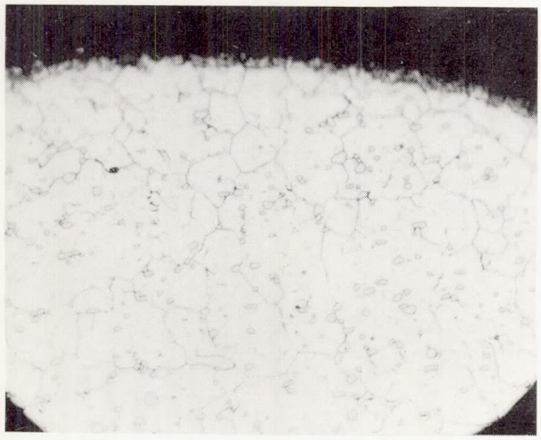
Trailing edge

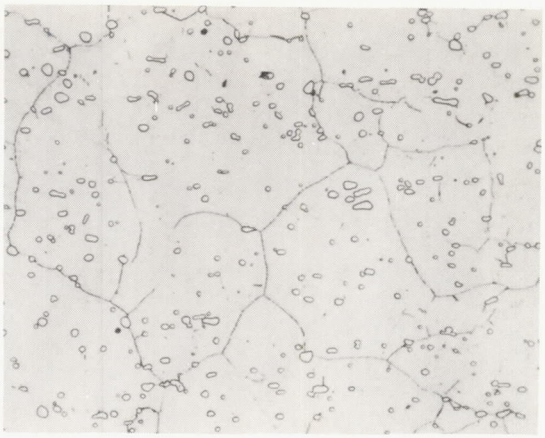
44 percent in printing.

of overtemperatured buckets.
X750.

4086

Tip





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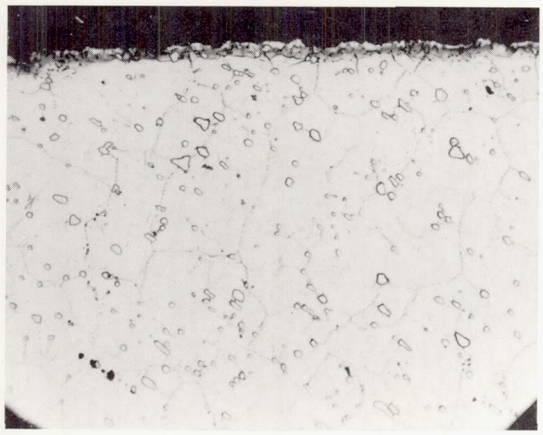

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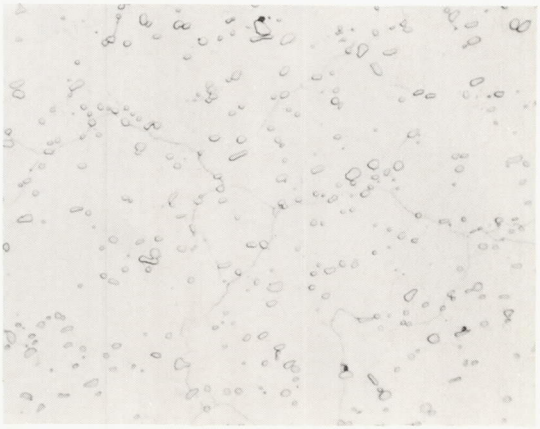


Leading edge

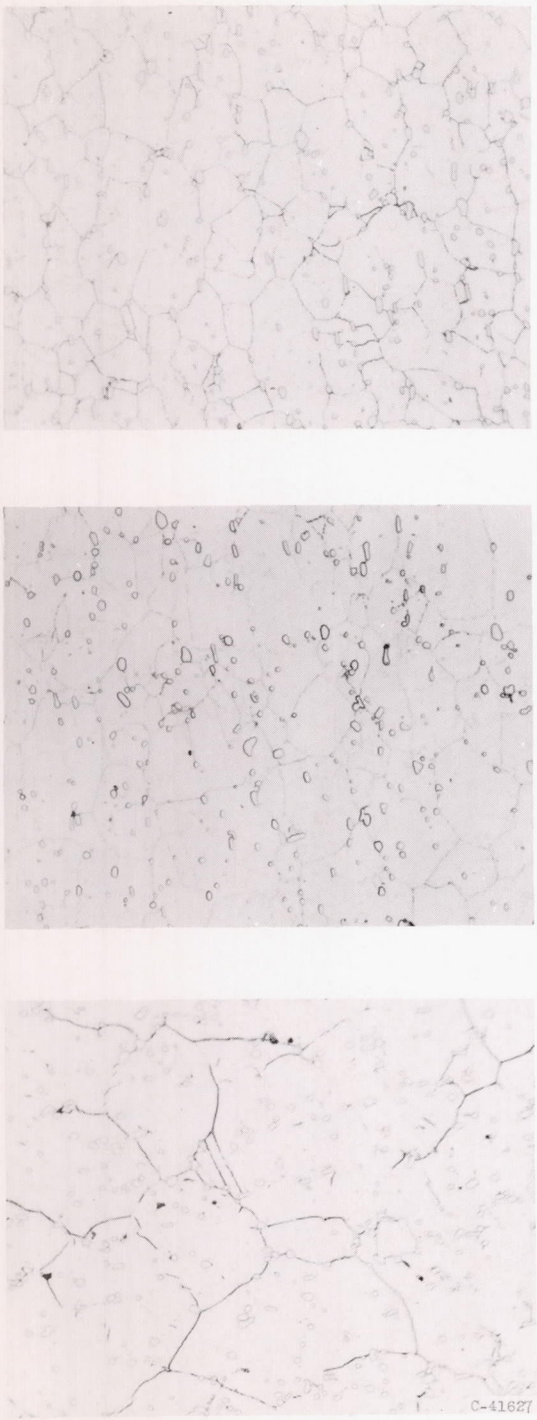
Middle

(j) Bucket 10. Reduced

Figure 6. - Continued. Microstructures
Etch, aqua regia plus glycerine.

4086

CR-5 back



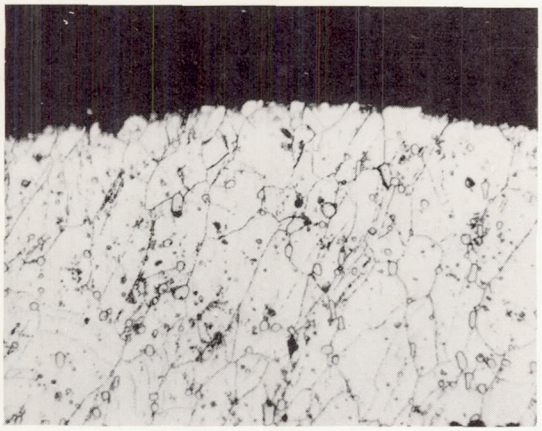
Trailing edge

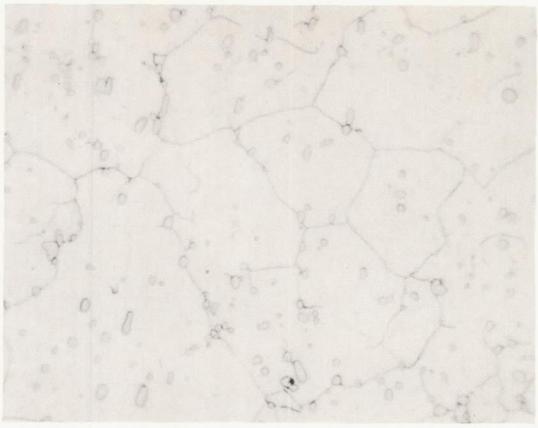
44 percent in printing.

of overtemperatured buckets.
X750.

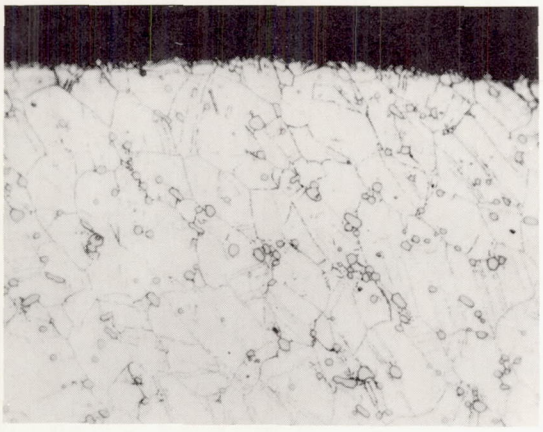
4086

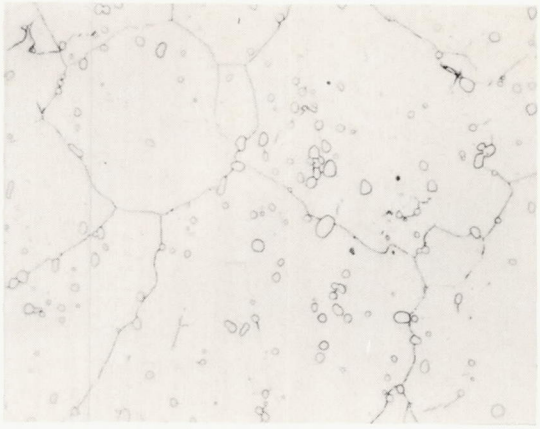
Tip





Mean





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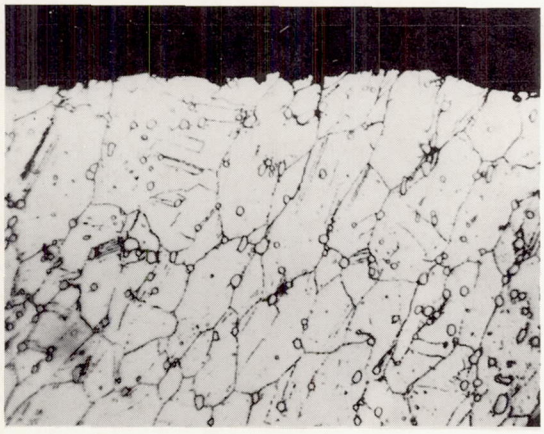


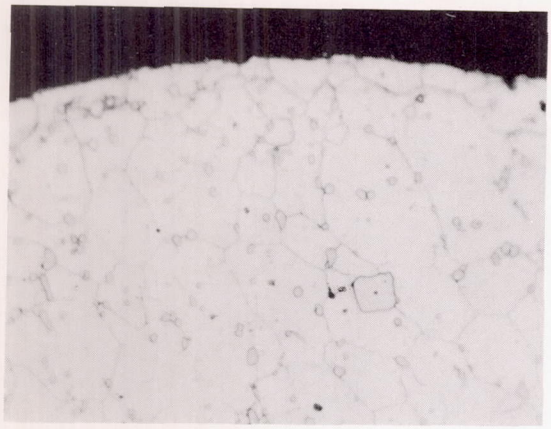
Leading edge

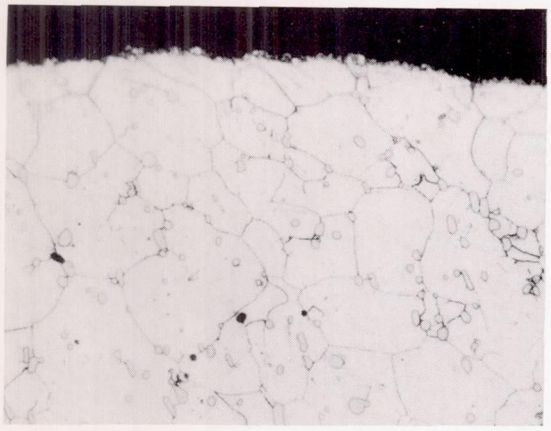
Middle

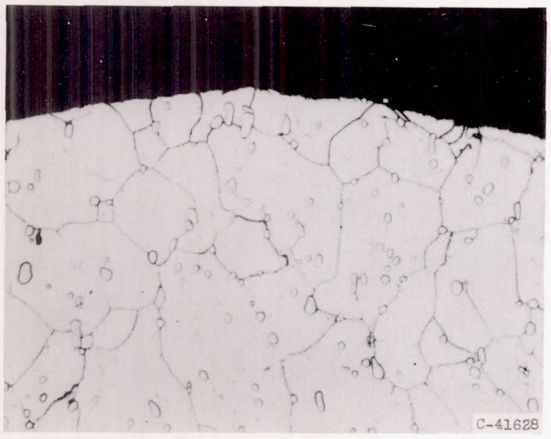
(k) Bucket 11. Reduced

Figure 6. - Continued. Microstructures
Etch, aqua regia plus glycerine.

4086







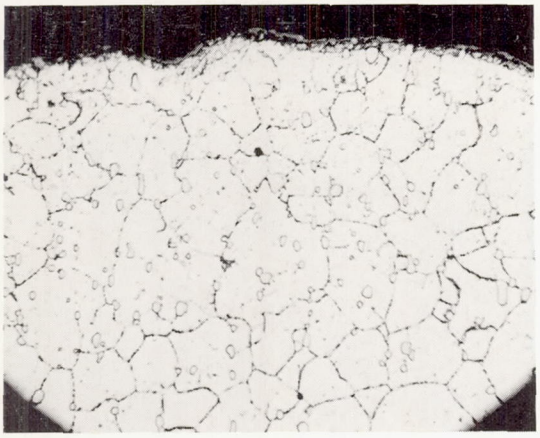
Trailing edge

44 percent in printing.

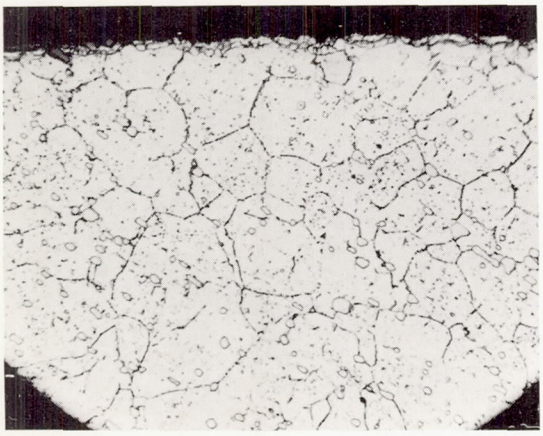
of overtemperatured buckets.
X750.

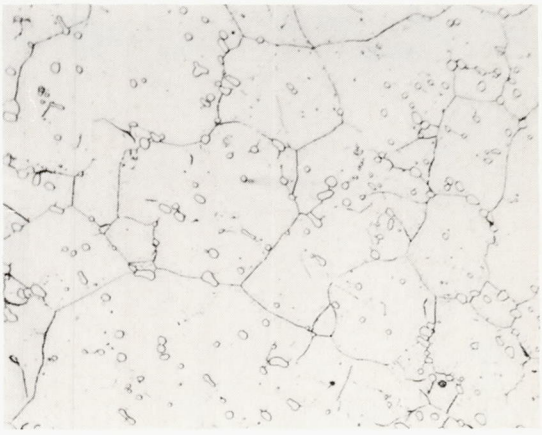
4086

Tip



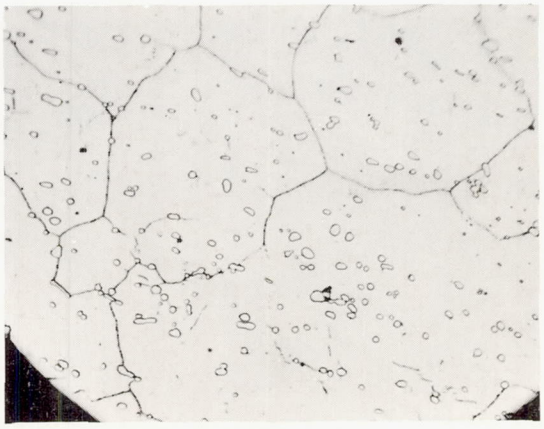
Mean





Hub

Leading edge



Middle

(l) Bucket 12. Reduced

Figure 6. - Concluded. Microstructures Etch, aqua regia plus glycerine.

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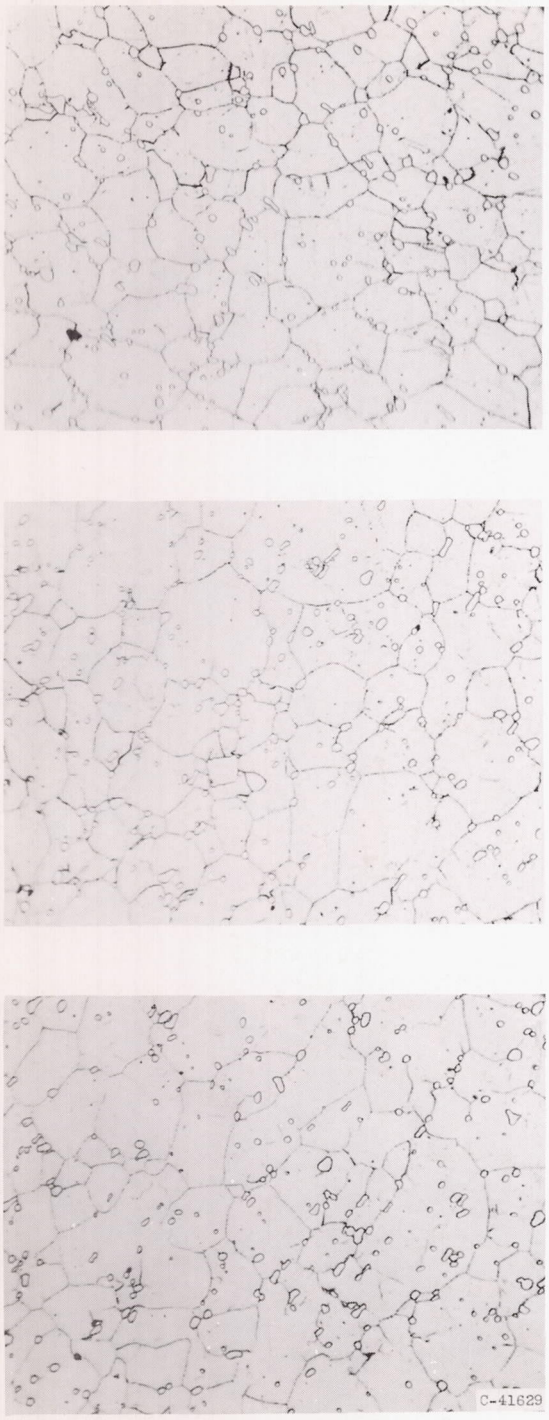
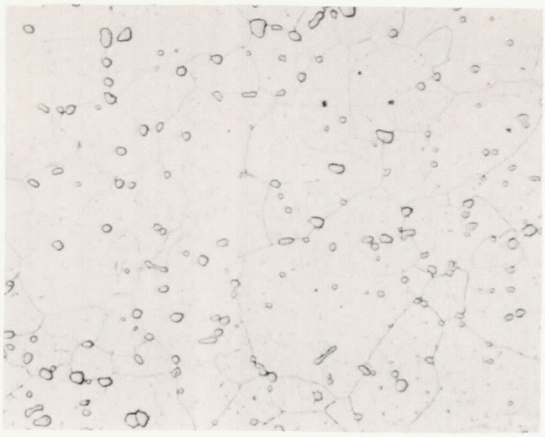


Trailing edge

44 percent in printing.

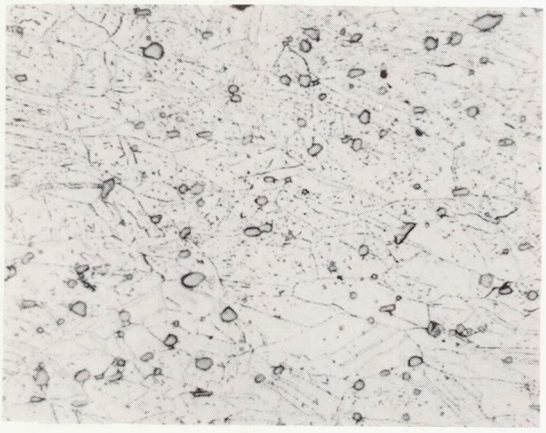
of overtemperatured buckets.
X750.

4086

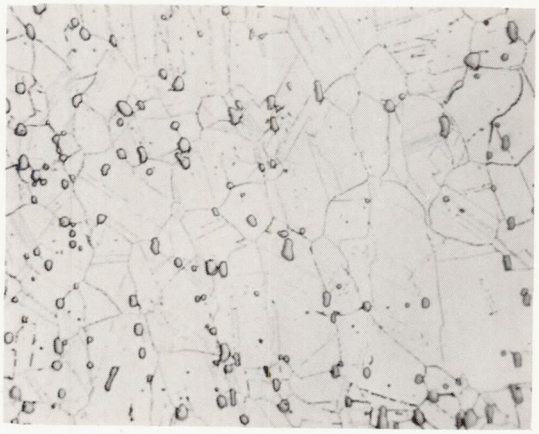


(a) Bucket 22, mean leading edge.

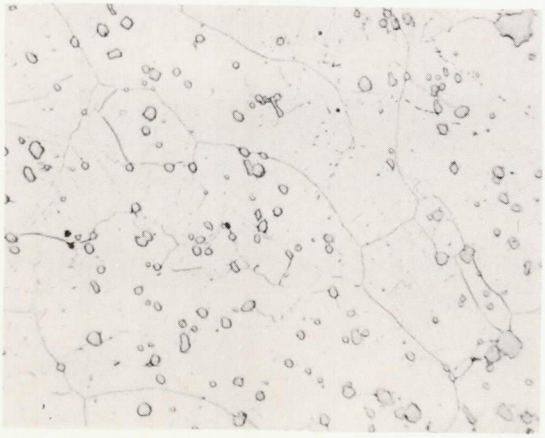
(b) Bucket 22, mean middle.



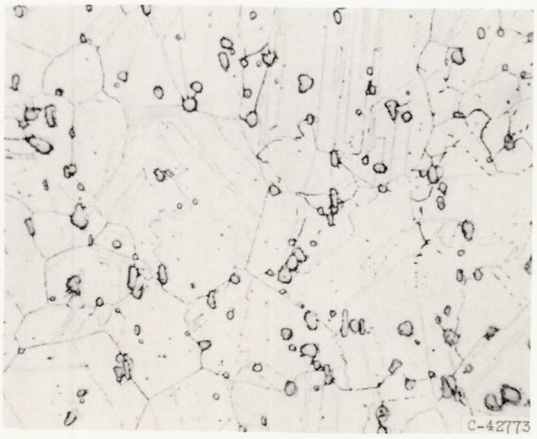
(c) Bucket 22, mean trailing edge.



(d) Bucket 23, mean leading edge.



(e) Bucket 23, mean middle.



(f) Bucket 23, mean trailing edge.

Figure 7. - Heat-treated specimens. Reduced 44 percent in printing. X750.

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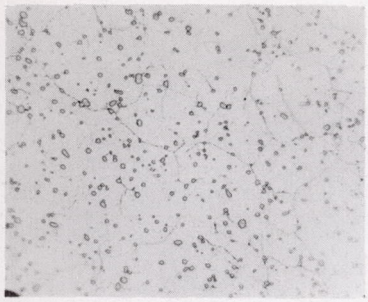
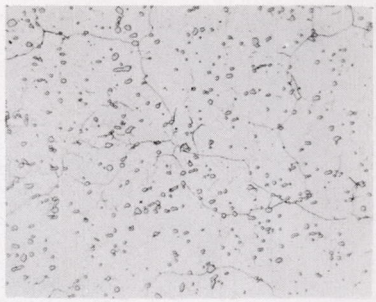
Rupture life, hr

Rupture life, hr

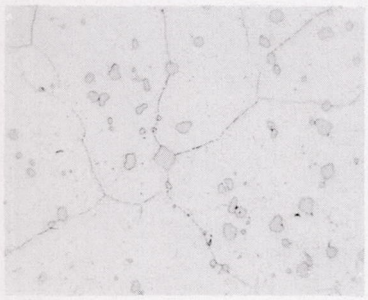
66

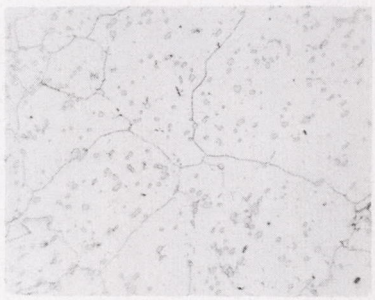




152.7

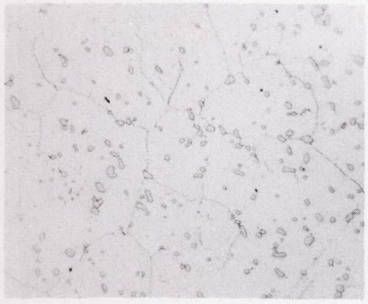
68.6

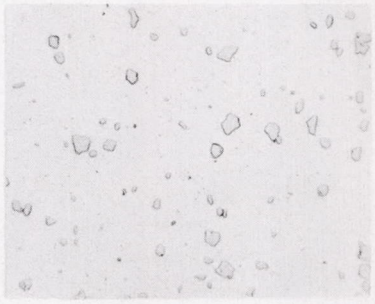




200.5

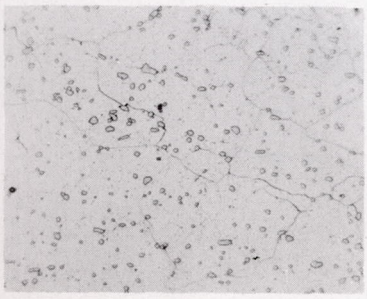
68.7

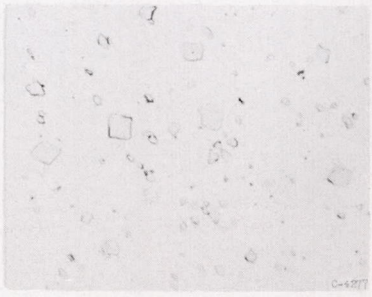




211.5

84.9





216.15

Figure 8. - Stress-rupture specimens arranged in order of increasing rupture life. Reduced 63 percent in printing. X750.