AN INTERIM REPORT ON INVESTIGATION OF LOW-TEMPERATURE SOLDERS FOR CRYOGENIC WIND TUNNEL MODELS

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ABSTRACT

The advent of high Reynolds number cryogenic wind tunnels has forced alteration of manufacturing and assembly techniques and eliminated usage of many materials associated with conventional wind tunnel models. One of the techniques affected is soldering.

Solder alloys commonly used for wind tunnel models are susceptible to low-temperature embrittlement and phase transformation. The low-temperature performance of several solder alloys is being examined during research and development activities being conducted in support of design and fabrication of cryogenic wind tunnel models. Among the properties examined during these tests are shear strength, surface quality, joint stability, and durability when subjected to dynamic loading. Results of these tests and experiences with recent models are summarized in this paper.

INTRODUCTION

The wind tunnel model manufacturing community utilizes solder technology for electrical connections, structural joining, and filling of aerodynamic surface imperfections. The advent of cryogenic wind tunnels, with the associated severe test environment and aerodynamic surface quality requirements which are well beyond those which are required for conventional wind tunnel models, severely impacts usage of solders on models. The low temperatures (-300°F) encountered in cryogenic wind tunnels cause embrittlement of many materials including most of the soft solders commonly used by model builders.

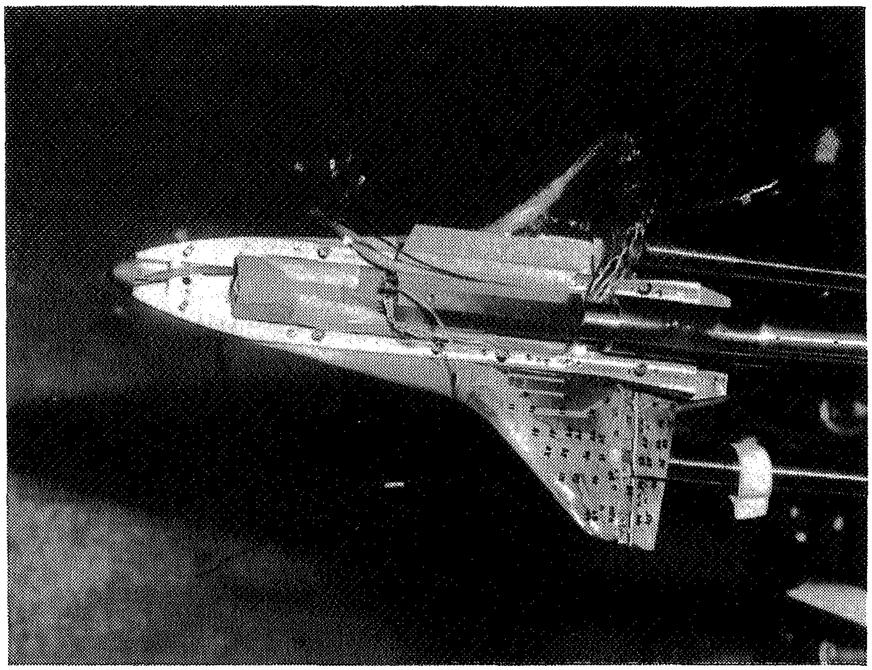
High tin alloys are often the preferred solders because of their good strength, hardness, wetting capabilities, finishing characteristics and appearance. Unfortunately, tin becomes brittle at a temperature well above the potential test temperatures in cryogenic facilities. Additionally, tin is susceptible to a low-temperature initiated crystalline transformation referred to as "tin pest" which results in a nonstructural "gray tin" powder. Additions of alloying elements are known to help alleviate both tin pest and low-temperature embrittlement.

High lead alloys remain ductile at cryogenic temperatures but exhibit poor wetting and finishing characteristics. Additions of selected alloying elements will serve to alleviate these problems, but will decrease low-temperature ductility.

Indium alloys are known to possess excellent low-temperature ductility and good wetting characteristics. However, indium alloys are soft and consequently exhibit poor finishing characteristics.

The purpose of this report is to discuss the efforts that are being made to identify and characterize soft solders suitable for cryogenic wind tunnel models. The solders being investigated include those embraced by conventional wind tunnel model fabricators as well as alloys which are known to possess low-temperature ductility.

ONE-PERCENT SPACE SHUTTLE MODEL



The most difficult surface imperfection to fill is created intentionally. Grooves are cut in an aerodynamic surface to facilitate routing of pressure tubing from the point on the surface point at which the static pressure is being measured to the location of the pressure transducer. Surface routing and solder filling is utilized whenever test requirements and model materials permit. The Shuttle model shown above, with upper fuselage removed, illustrates the usage of solder to fill the tubing grooves (lighter areas on wing).

FILLING MATERIALS COMPARISONS

	BRAZE ALLOYS	SOLDER ALLOYS	POLYMERIC FILLER
PLUSES	Strength Hardness Conductivity Coefficient of thermal expansion	Moderate heat Conductivity Coefficient of thermal expansion	Low heat Application
MINUSES	Heat Facilities Permanent	Corrosive fluxes Soft	Coefficient of thermal expansion Soft

The three types of materials generally considered for filling surface imperfections in wind tunnel models are braze alloys, soft solders, and polymers. A comparison of the advantages and disadvantages of each with respect to cryogenic models is tabulated above. This comparison reveals that selection of a filler is dependent on the particular application and in all likelihood will not be a clear-cut decision.

The shear strength of soldered joints should match or exceed that of bonded joints, but will not approach that of brazed joints and, therefore, should be used cautiously as a primary structural joining technique. Solders do not require heat levels high enough to cause model distortion or alteration of base metal properties. The thermal conductivity of a typical solder matches closely the conductivities of model base metals. The typical solder's coefficient of thermal expansion is approximately twice that of the base metal or less than forty percent of the typical polymer's coefficient. For most applications the contraction differential between base metal and solder will cause no structural problems but could prove to be a problem with respect to local surface "dimpling" at low temperatures. Of greater concern with regard to surface quality is dimpling caused by the difference in hardness between the solder and model base metal. This differential induces undercutting of the filled areas during hand finishing of contoured surfaces. The softness of solders falls in between that of braze alloys and polymers. The chief disadvantage associated with solders is the necessity of using corrosive fluxes for preparing most of the cryogenic model metals for soldering. The corrosion induced by flux residues and entrapped flux has been a persistent problem and can only be alleviated by exacting joint design, meticulous soldering procedures, and thorough post soldering cleaning.

PROGRAM GOALS

- O IDENTIFY SOLDER ALLOYS SUITABLE FOR CRYOGENIC WIND TUNNEL MODELS
- O DETERMINE LOW-TEMPERATURE PROPERTIES OF SUITABLE ALLOYS

As solder alloys have been determined to have some redeeming values as a wind tunnel model filler material, a program was initiated to investigate solders and their usage at cryogenic temperatures. The initial goal of the investigation is to identify solder alloys suitable for usage on cryogenic wind tunnel models. The final goal is to characterize the low-temperature mechanical properties of the suitable alloys.

HIGH TIN SOLDERS

ADVANTAGES: WETTABILITY
WIDE USAGE
STRENGTH

DISADVANTAGES: TIN PEST
LOW TEMPERATURE
EMBRITTLEMENT

SOLDERS CONSIDERED: 97% Sn 3% Ag
95% Sn 5% Sb

Solders with a high tin content are attractive because of their inherent good wetting characteristics, relatively high tensile strength, good surface finishing characteristics, and the level of experience with these alloys that is held by wind tunnel model fabricators. Offsetting these advantages is the susceptibility of tin to low-temperature embrittlement and "tin pest."

Tin-based solder alloys typically become brittle at temperatures slightly below the freezing point of water. This embrittlement dictates that usage is to be limited to components exposed to low stress levels. The tin pest problem is a low-temperature crystalline structure transformation which results in white tin being transformed to gray tin powder. This transformation can be alleviated by addition of alloying elements, most notably, antimony.

The two high tin alloys investigated in this program were 97% tin-3% silver and 95% tin-5% antimony. These two alloys were chosen because of their high strength, good wetting, and good surface finishing characteristics.

TIN/LEAD SOLDERS

ADVANTAGES: INCREASING DUCTILITY
AVAILABILITY

DISADVANTAGES: SOFTNESS
DECREASING WETTABILITY

SOLDERS CONSIDERED: 49.5% Pb 50% Sn .5% Sb
93% Pb 5.2% Sn 1.8% Ag

The tin-lead solder alloys exhibit increasing low-temperature ductility with increasing lead content. Alloys with over 70% lead are ductile at temperatures approaching absolute zero. Tin-lead alloys containing lead in excess of 40% are generally considered to be "wiping" solders and are frequently used in plumbing and filling of gaps on automotive bodies. Unfortunately, solders with a high lead content are soft, which complicates surface finishing, and exhibit greatly reduced wetting characteristics.

A 49.5% lead-50% tin-0.5% antimony solder alloy has been examined during this program because of its position between high tin and high lead content alloys according to existing mechanical property data. A high lead solder, 93% lead-5.2% tin-1.8% silver, will be investigated in the near future.

INDIUM SOLDERS

ADVANTAGES: DUCTILITY
LOW HEAT
BASE MATERIALS

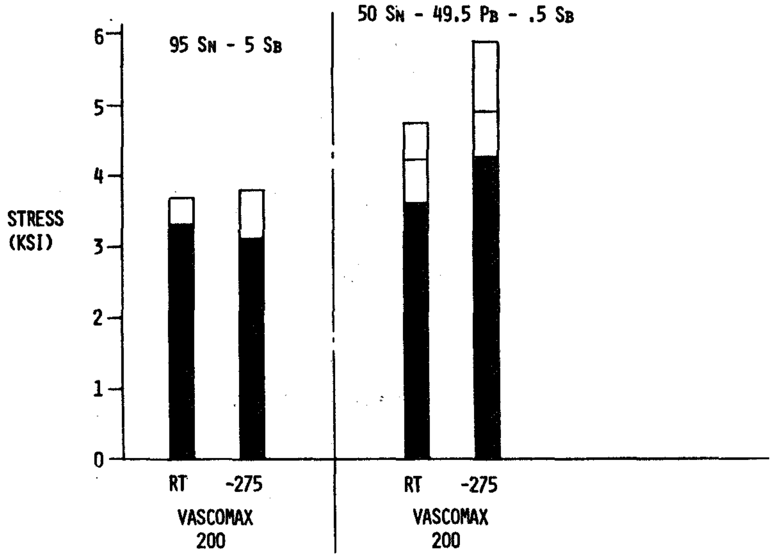
DISADVANTAGES: SOFTNESS
COST
EXPERIENCE

SOLDERS CONSIDERED: 37.5% Pb 37.5% Sn 25% In
50% Pb 50% In

Indium-based solder alloys offer greatly improved ductility at cryogenic temperatures, intermediate melting temperatures, and the capability to join a variety of base materials. Complicating the usage of indium solders is the extreme softness of the material with respect to the model base material. Additional considerations which may make the indium alloys less than the optimum choice are the high cost and the lack of fabrication experience with these solders.

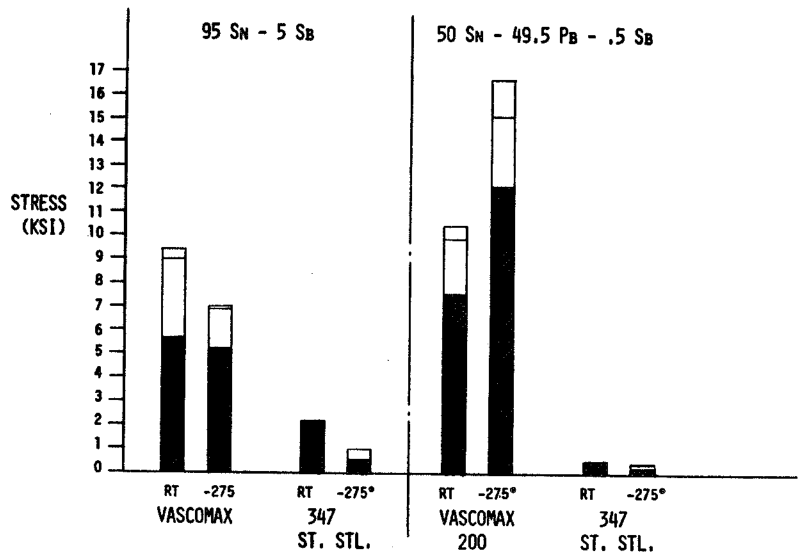
Among the indium alloy solders to be examined in this program are a 37.5% lead-37.5% tin-25% alloy and a 50% lead-50% alloy. The lead-tin-indium alloy is expected to have a good combination of mechanical properties and the lead-indium alloy is expected to have excellent ductility and acceptable wetting characteristics.

SOLDER - SHEAR TEST



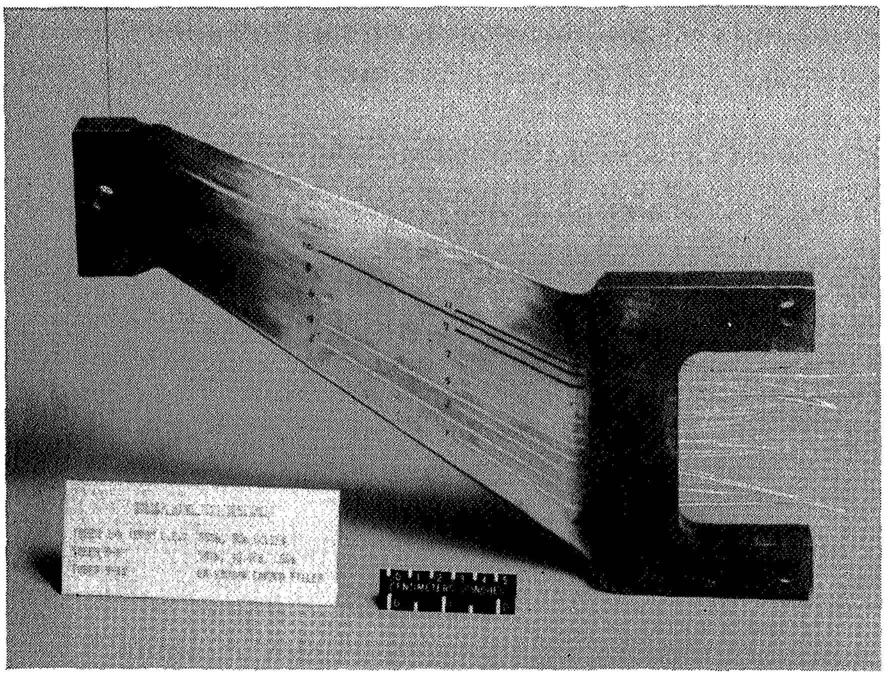
A limited number of lap-shear tests involving 18% nickel maraging steel specimens (VASCOMAX) joined with 95% tin-5% antimony and 50% tin-49.5% lead-0.5% antimony solders provided some surprises. Contrary to expectations, the tin-antimony alloy shear strength was less than that of the tin-lead-antimony alloy at room temperature and did not demonstrate an increase at cryogenic temperatures. The tin-lead-antimony alloy did demonstrate an increase in shear strength at cryogenic temperatures, but not to the degree expected. A disturbing development was the scatter of data. In the bar graph above, the shaded portion of the bars represents the minimum strength, the top of the bars represents the maximum strength and the line in-between indicates the average shear strength. The data band width for the tin-antimony alloy at the cryogenic temperature tests was approximately 50% of the average value.

SOLDER - TENSILE TEST



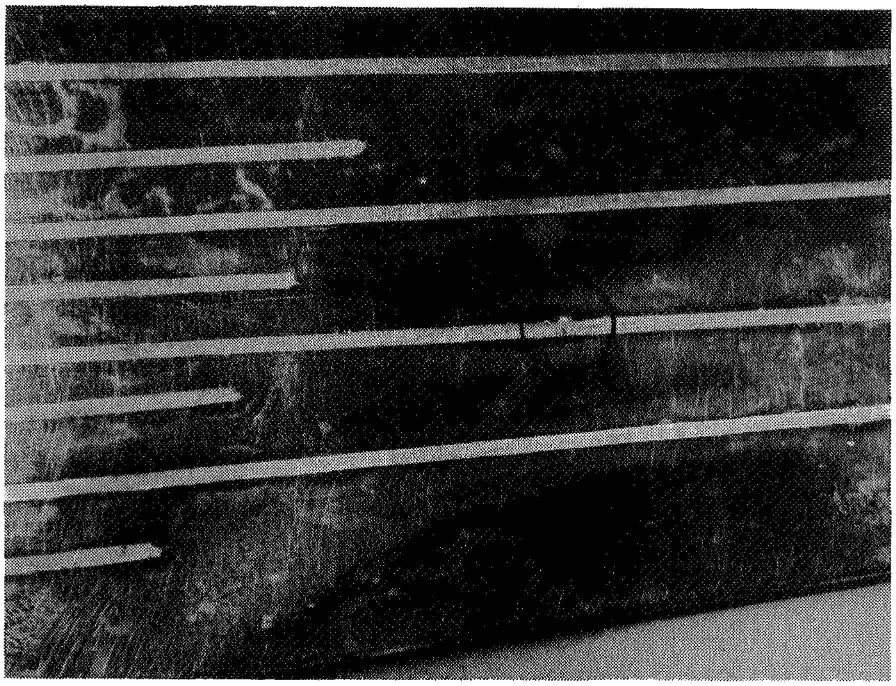
Similarly, tensile strength tests were conducted at room and cryogenic temperatures with the same solder alloys being used to join 18% nickel maraging steel specimens and 347 stainless-steel specimens. The bar graph of the test data indicates the same tendencies which were evident in the shear test data. Generally, the tin-lead-antimony alloy performed about as expected for the 18% nickel maraging steel specimens and the tin-antimony alloy did not meet expectations. Especially disappointing were the tensile strengths measured for the stainless-steel specimens. Also troubling, once again, was the scatter of data for the maraging steel specimens. Examination of the tested specimens revealed poor joint quality. The joint quality can be attributed to several factors: large joint area contributed to flux entrapment and void formation, improper surface finishing impeded solder flow, and specimen size which made uniform heating difficult. These factors are being addresed and will be minimized in future testing.

DYNAMIC MODEL WING SPECIMEN



A dynamic test at cryogenic temperatures was conducted to determine suitability of the tin-antimony and tin-lead-antimony alloys for covering surface routed grooves in a wind tunnel model. A simulated model wing made with VASCOMAX, with tube grooves filled with the two solders and a modified epoxy, was used for this test. The specimen was clamped at the root end in a loading fixture. The assembly was lowered into a cryostat and allowed to reach equilibrium at approximately -300°F. A load was then applied to the block of material at the wing tip at a rate of 12 cycles per minute for 5 thousand cycles. This sequence was repeated to give 5 thousand cycles at each of 4 levels of loading. The loading levels represented specimen surface bending stress levels of 22, 44, 66, and 88 thousand pounds per square inch.

DYNAMIC MODEL WING SPECIMEN - LIQUID DROPLET



A test of the simulated wing specimen was uneventful and surprisingly successful. There were no structural failures. No filled area separated or moved relative to the specimen surface, nor was any cracking of the solders or epoxy observed. However, there was formation of liquid droplets, circled in the photograph, along the tin-antimony solder filled grooves. These droplets were determined to be acidic and apparently were the result of flux entrapment in the solder joint. Under thermal cycling between room and cryogenic temperatures, the joint apparently developed microcracks allowing moisture to migrate to entrapped flux through capillary action. This acidic solution then gradually seeped to the surface over an extended period of time. These droplets were evident throughout the 95% tin-5% antimony joints, but appeared in only three spots on the 50% tin-49.5% lead-0.5% antimony soldered areas.

CONCLUSIONS

- O SOLDER ALLOY SUITABLE FOR CRYOGENIC WIND TUNNEL MODELS HAS BEEN IDENTIFIED
- O STRUCTURAL PROPERTIES DEPENDENT ON TECHNIQUE/EXPERIENCE

The program thus far has identified 50% tin-49.5% lead-0.5% antimony as a common solder which can be utilized for filling surface flaws and tube grooves in cryogenic wind tunnel models. Other alloys which should be suitable will be investigated as this program continues.

The program has served to reemphasize the fact that structural properties are as dependent on technique as they are on any other factor. Strict adherence to procedures to be developed for cryogenic wind tunnel model application will be required in order to achieve acceptable solder joints.

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