INITIAL INVESTIGATION OF CRYOGENIC WIND TUNNEL MODEL FILLER MATERIALS

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ABSTRACT

Filler materials are commonly used to fill surface flaws, instrumentation grooves, and fastener holes in wind tunnel models. More stringent surface quality requirements and the more demanding test environment encountered in cryogenic wind tunnels eliminate usage of filler materials such as polyester resins, plaster, and waxes which are used on conventional wind tunnel models. In order to provide a material data base for cryogenic models, various filler materials have been investigated for their applicability.

Surface quality requirements and test temperature extremes require matching of coefficients of thermal expansion for interfacing materials. Microstrain versus temperature curves have been generated for several candidate filler materials for comparison with cryogenically acceptable materials. Matches have been achieved for aluminum alloys and austenitic steels.

Simulated model surfaces have been filled with candidate filler materials for determination of finishing characteristics, adhesion and stability when subjected to cryogenic cycling. Filler material systems have been identified which meet requirements for usage with aluminum model components.

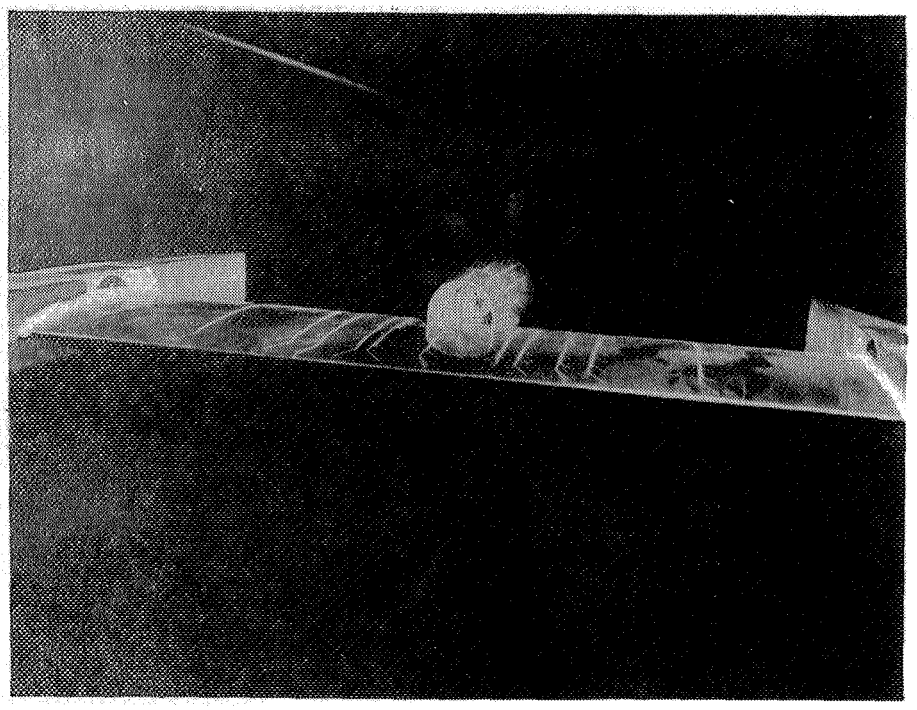
INTRODUCTION

Aerodynamic research models require smooth, continuous surfaces to minimize surface-induced flow disturbances. Flaws in surfaces of conventional wind tunnel models have been satisfactorily filled with waxes, plasters, and plastic body filler. However, the National Transonic Facility (NTF), with its unique capabilities and test environment, renders such common materials unsuitable.

The NTF has high Reynolds number capabilities which require higher surface contour fidelity and finish than is required in conventional facilities. The NTF also operates at cryogenic temperatures; this causes the conventional filler materials to become brittle, lose contour fidelity because of greater thermal contraction than primary structural materials, and suffer bond failure because of thermally induced stresses.

A program was initiated at Langley Research Center to identify or develop materials which could be used to fill imperfections on cryogenic wind tunnel models. The initial phase of the program was completed with the identification of two suitable filler materials. During this phase, candidate materials were examined for structural and dimensional stability, ease of use, surface quality, and usage limitations.

CONVENTIONAL WIND TUNNEL MODEL
WITH FILLED INSTRUMENTATION GROOVES



Often surface flaws are created intentionally as shown in the figure above. In this 16-Foot Transonic Tunnel model, grooves were cut in the wing and engine nacelle surfaces for routing static pressure orifice tubes from the points being monitored to the pressure transducers. Other intentional flaws would include fastener and dowel holes as well as reference (fixturing) holes. This model was filled with a commercial epoxy which, unfortunately, becomes brittle at low temperatures thus precluding its use in NTF models.

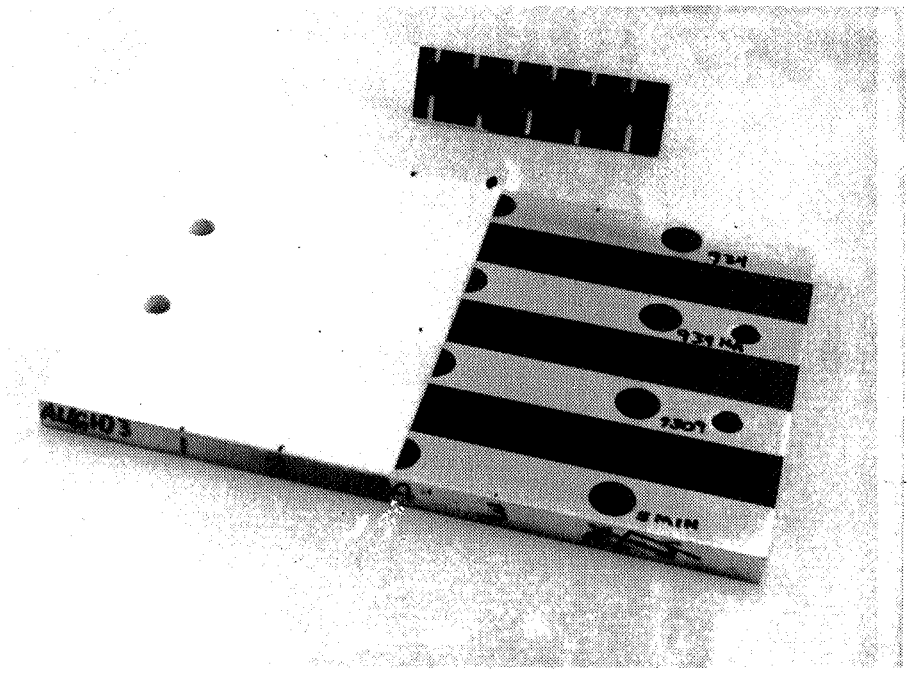
PROGRAM GOAL

PROGRAM GOAL: IDENTIFY/DEVELOP FILLER MATERIALS SUITABLE FOR CRYOGENIC MODELS

- **ADHESION**
- **STABLE SURFACE**
- **HAND FINISHING**
- **RAPID REMOVAL/REPLACEMENT**

Realizing the necessity of filling flaws and the inadequacies of the conventional model filler materials, the current program was initiated with a simply stated goal, "Identify and/or develop materials which will be suitable for cryogenic wind tunnel models." The primary factors which need to be considered when evaluating a filler material's suitability are: 1. Adhesion throughout the test environment. 2. Dimensional stability of the filler material upon exposure to thermal and tensile cycling. 3. The difficulty of hand finishing the material at the test facility. 4. The capability of rapid removal and replacement to allow quick model configuration modifications.

SCREENING SPECIMEN

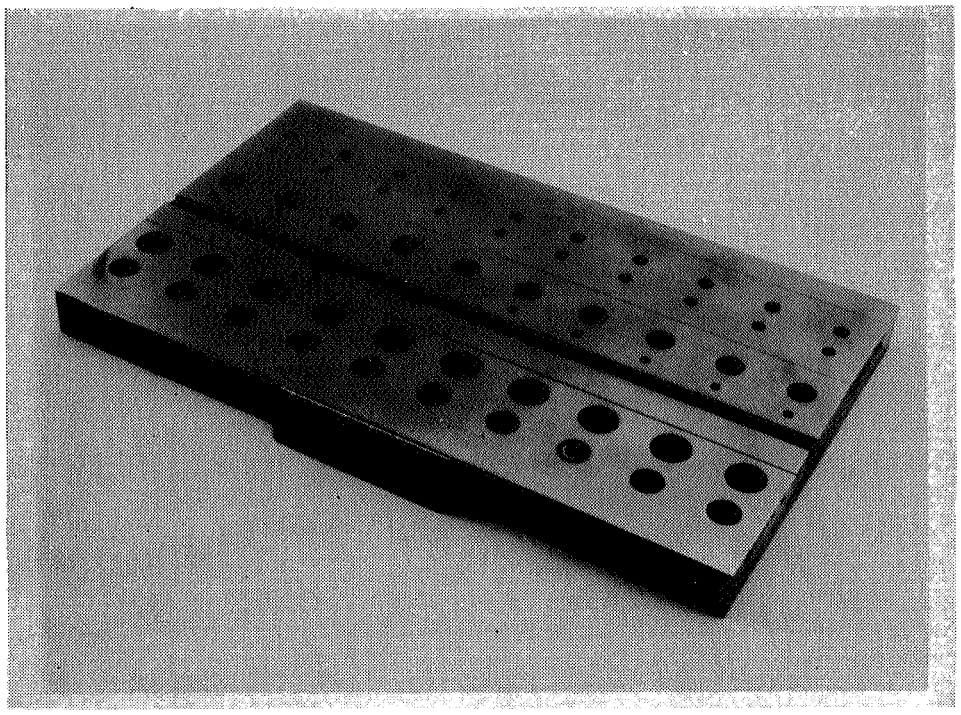


A simple specimen configuration was used to make an initial evaluation of a candidate filler material's suitability. This specimen consisted of a flat rectangular plate of an acceptable cryogenic model structural material with a series of counterbored holes and grooves. The grooves and holes were filled with the filler(s) being evaluated and are hand polished. The finished sample was measured with a profilometer which provided a recording of the contour and surface finish. The specimen was then thermally cycled between room and cryogenic temperatures several times and subsequently remeasured in the profilometer. The before and after recordings of surface contour and finish were compared for detection of filler instability.

These specimens have been utilized to test commercial metal filled epoxies, waxes, low-temperature structural adhesives and quick setting epoxies modified with additions of aluminum, steel, and talc powders as well as carbon spheres. Only one commercial product, Belzona "Super Metal"; one structural adhesive, Hysol "EA 9309", filled with carbon, steel or talc; and a fast-setting epoxy, Hardman "Extra-Fast-Setting", filled with carbon passed this screening test. The common mode of failure was fracture of the bond line.

The carbon filled adhesives did not meet the surface finish requirements due to the spheres creating a pebbled surface. The specimen shown above was one of many which was painted with an acrylic lacquer to improve the surface finish and successfully tested.

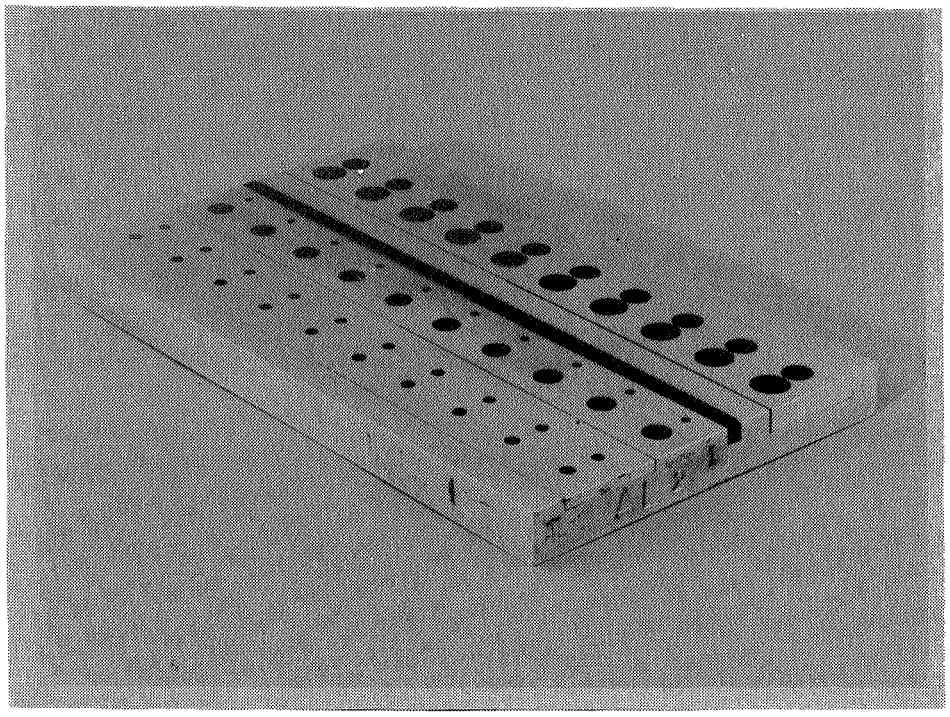
FLAT PLATE SPECIMEN



The flat plate specimens were used to continue testing of filler materials which survived the screening evaluation. This configuration, which is more representative of an actual model, incorporated cover-plates with deliberate gaps around the perimeter, surface grooves, and various fasteners with submerged heads. The specimen was filled, measured, thermally cycled, and remeasured in the same manner as the screening specimens.

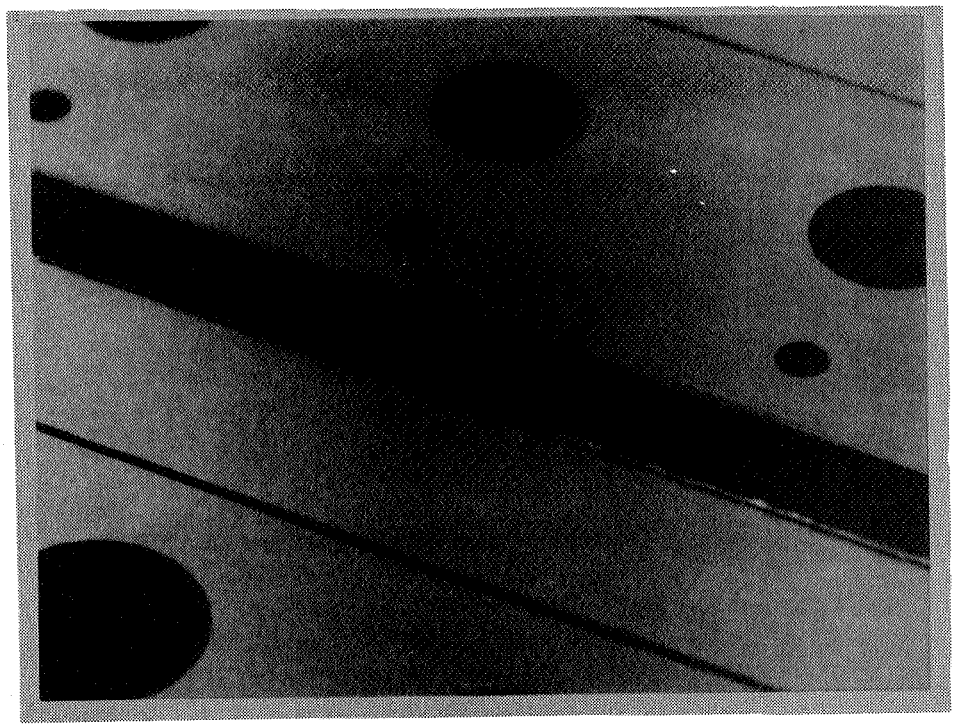
The best performing filler material tested with this specimen configuration has been EA 9309 filled with steel or carbon. Belzona "Supe Metal" has not been tested with this specimen configuration.

FLAT PLATE SPECIMEN
WITH BOND LINE FAILURE

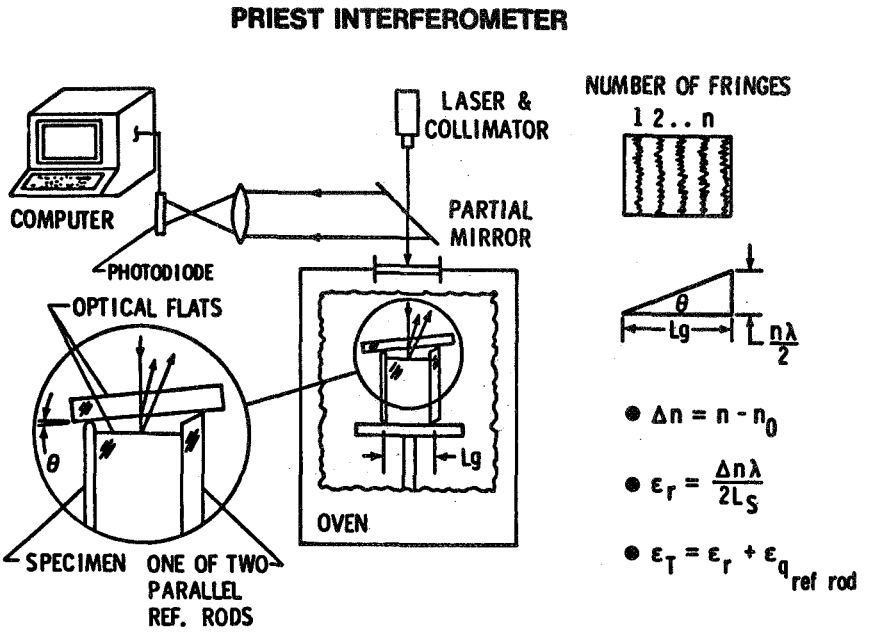


As mentioned previously, a number of tests resulted in elimination of several filler materials due to shrinkage, bond line fracture, and/or instability. It is worth noting that these specimens were static specimens and were only subjected to thermally induced stresses. The aluminum specimen shown above had one side filled with an aluminum powder and structural adhesive mixture and the other side filled with the same structural adhesive mixed with steel powder. This particular specimen suffered a bond line failure along the wide surface groove and movement of the filler which can be seen easily in the close up on the next page.

CLOSE UP - FLAT PLATE
WITH BOND LINE FAILURE



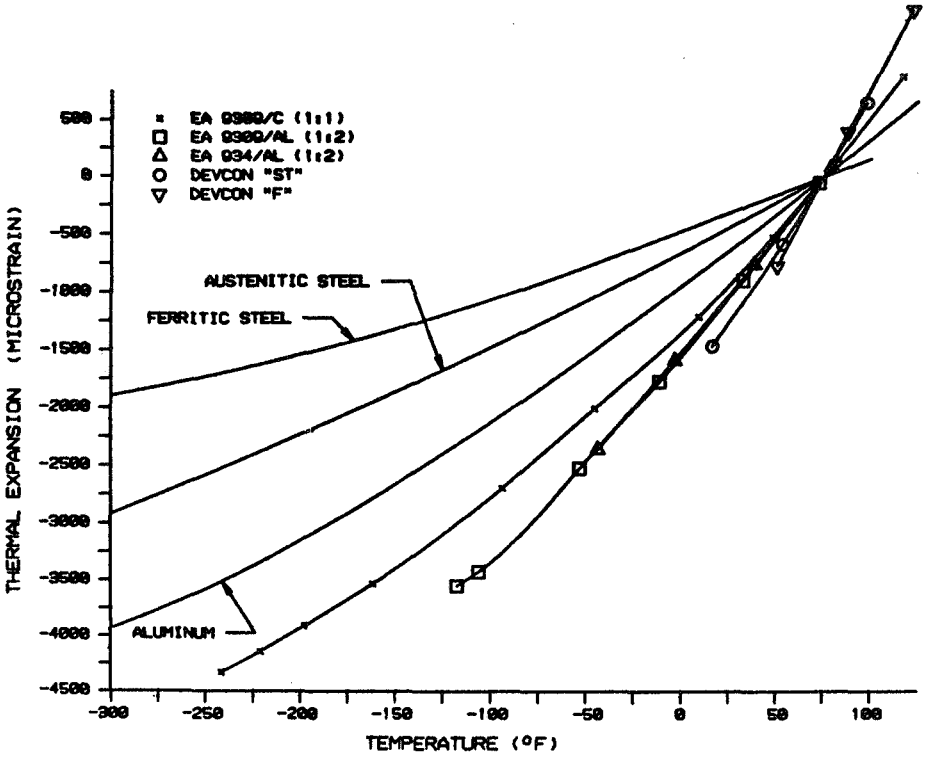
The bond line fractured and the filler material moved with respect to the metal surface during the thermal cycling. This type of failure was quite common, but seldom as dramatic as in this specimen. Failures of this type are attributed to stresses created by the mismatch of coefficients of thermal expansion between the metal plate and the filler material and the resultant relative contraction.



After experiencing several disappointments with the flat plate specimens which were related to mismatched coefficients of thermal expansion, it became obvious that the coefficients of the various candidate filler materials needed to be determined. The information generated would assist in matching filler materials to substrate metal, eliminating various fillers from further consideration, and determining optimum epoxy-to-filler ratios.

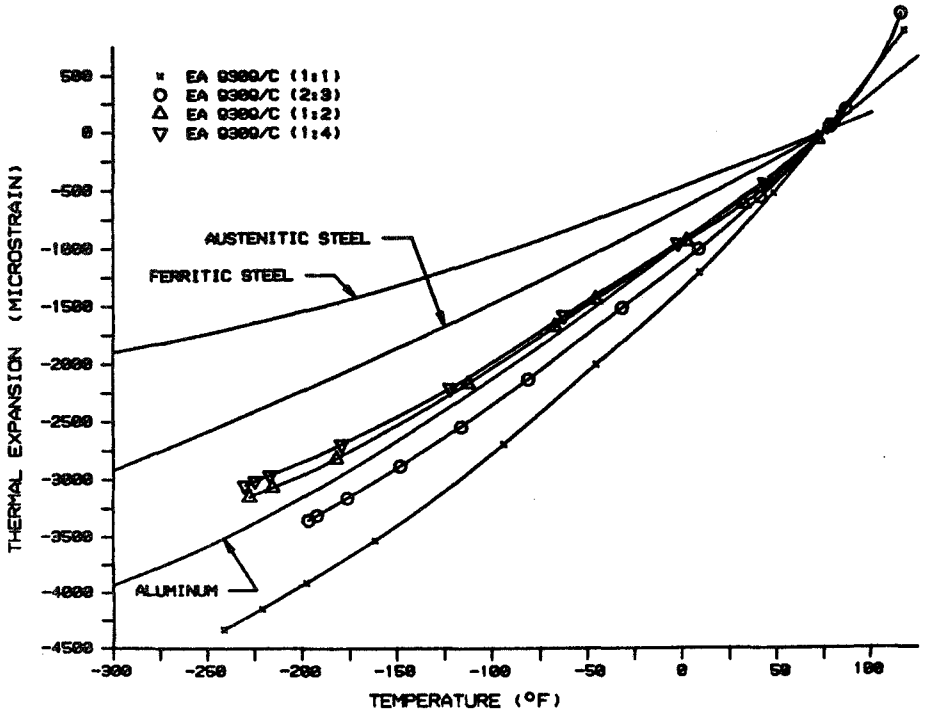
The device which was used to measure the coefficients of thermal expansion is shown schematically above. Briefly, an optical flat is supported on two reference rods and a specimen rod of the material being measured. As the temperature is changed the length of the specimen rod changes with respect to the reference rods, tilting the optical flat. The increasing tilt angle creates an increase in the number of interference fringes resulting from the reflected laser beam. A photodiode counts the number of fringes which is then used to calculate the relative contraction of the specimen with respect to the reference rods.

THERMAL EXPANSION VERSUS TEMPERATURE
OF VARIOUS METAL FILLED ADHESIVES



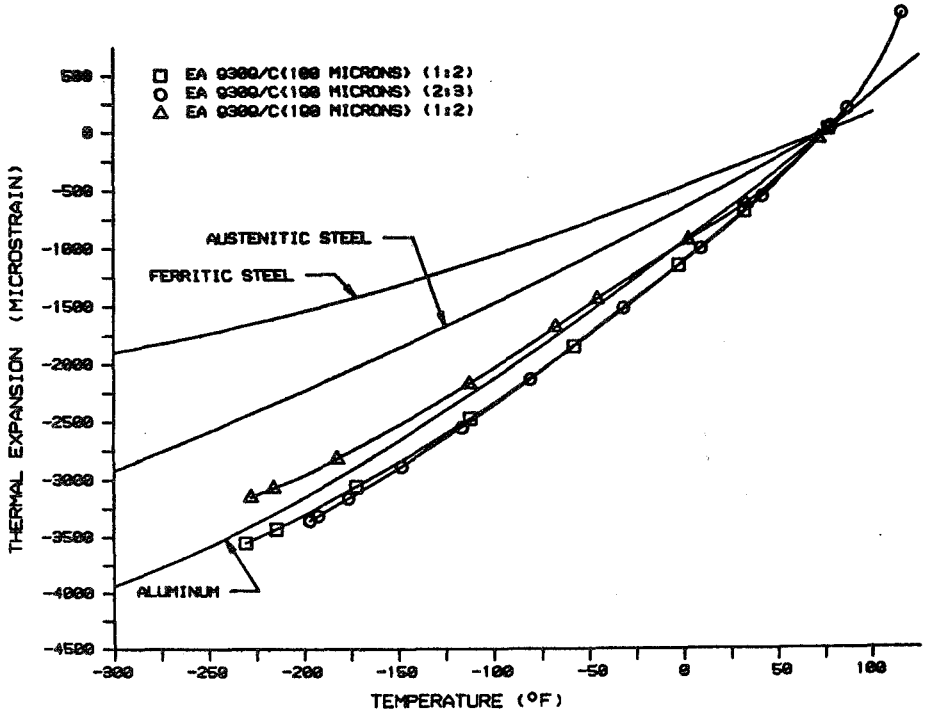
The first candidate filler materials examined for determination of coefficient of thermal expansion were two commercial metal filled epoxies, two aluminum filled structural adhesives, and a carbon filled structural adhesive. As can be seen in the graph, the carbon filled structural adhesive performed better than any of the metal filled systems. It should be noted that the epoxy-to-filler ratios given are weight ratios. Thus, the aluminum filled structural adhesives and the carbon filled structural adhesive had about the same epoxy-to-filler volume ratio.

THERMAL EXPANSION VERSUS TEMPERATURE OF EA 9309 WITH VARIOUS CONCENTRATIONS OF CARBON SPHERES



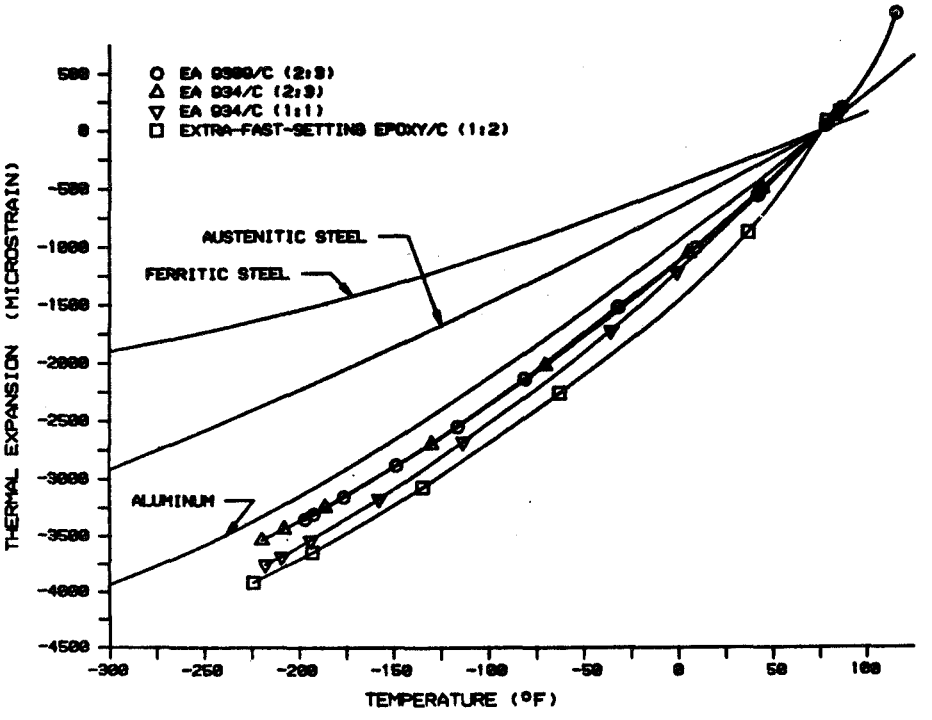
A series of tests were run on the filler material which came the closest to matching aluminum's coefficient of thermal expansion to determine the effect of varying the epoxy-to-filler ratio. As can be seen in the graph, an increase in the amount of carbon above a 1:2 epoxy-to-filler ratio resulted in no significant decrease in the rate of contraction. Shear specimen tests were conducted to determine the effect of varying the carbon concentration and revealed a significant reduction in shear strength when the carbon content was increased beyond the 1:2 epoxy-to-filler ratio. The higher ratios also proved to be difficult to mix and apply due to the dryness of the resulting mixture.

THERMAL EXPANSION VERSUS TEMPERATURE
EFFECTIVENESS OF VARYING GRAIN SIZE



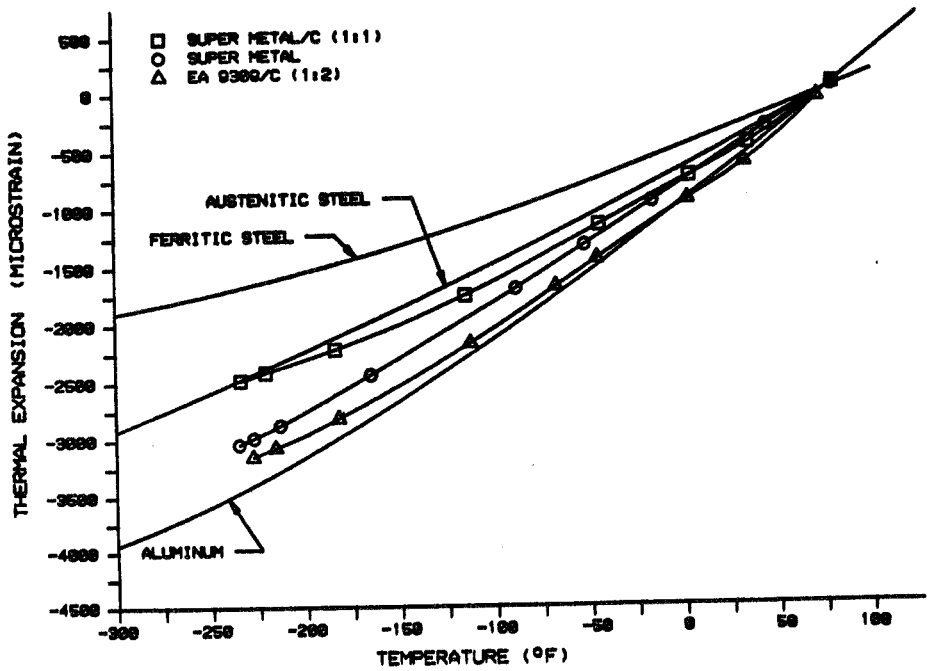
The effects of particle size were examined using 190 micron and 100 micron carbon spheres. The 190 micron size spheres were more effective than the 100 micron size spheres using the same epoxy-to-filler ratios by weight. Additionally, the smaller sphere size tended to saturate the epoxy at lower concentrations resulting in extremely dry mixtures. The smaller grain size was attractive from the stand point of offering a better surface finish, but its general ineffectiveness and dryness precluded its further evaluation.

THERMAL EXPANSION VERSUS TEMPERATURE OF THREE CARBON FILLED ADHESIVES



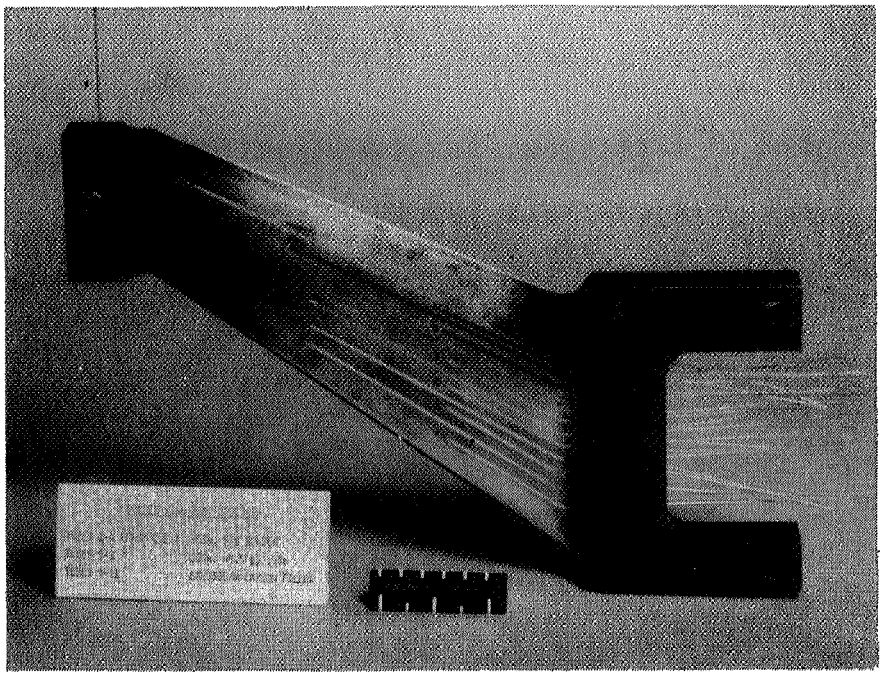
Evaluation of the effects of the addition of the 190 micron carbon spheres to three different epoxy systems revealed that the two structural adhesives' contraction rates were modified by the same amount. The third epoxy, a fast setting system, was not as effectively altered, but did perform better than the commercial products examined previously. Shear tests indicated that each of these systems had a shear strength in excess of 2 thousand pounds per square inch at both room and cryogenic temperatures. Of the systems examined here, the carbon filled EA 934 was the most difficult to use as the already thick fiber filled system became extremely dry with the addition of the carbon.

THERMAL EXPANSION VERSUS TEMPERATURE
FILLER MATERIALS OFFERING BEST MATCHES WITH BASE METALS



Recently a commercial product was identified which provides a near match with the coefficient of thermal expansion of aluminum and austenitic steels. The product, Belzona "Super Metal", was also modified by being filled with carbon spheres to reduce its coefficient even lower. This effort did reduce its contraction rate, but resulted in a saturated mixture which was difficult to apply and had virtually no shear strength. The unmodified product has the same shear strength as the carbon filled structural adhesive systems.

DYNAMIC TEST SPECIMEN



A dynamic test at cryogenic temperatures was conducted to determine suitability of the carbon filled EA 9309 for covering instrumentation grooves in a stressed wind tunnel model. A simulated model, with grooves filled with two solders (from a parallel development program) and the carbon filled EA 9309, was used for this test. The specimen was clamped at the right 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 on the left end 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. The carbon filled EA 9309 passed this extremely demanding test with no indication of any degradation.

SUMMATION

- **EA 9309/C: ACCEPTABLE FOR MOST CRYOGENIC APPLICATIONS**
- **EXTRA-FAST-SETTING EPOXY/C: ACCEPTABLE FOR FILLING HOLES**
- **SUPER METAL: POTENTIAL FOR WIDE CRYOGENIC APPLICATIONS**

The EA 9309 modified by the addition of 190 micron carbon spheres in a 1:2 epoxy-to-carbon weight ratio has proven to be acceptable in terms of adhesion, stability, and capability to be worked by hand. Its primary drawbacks are its long curing cycle and the necessity of using a glazing compound or lacquer over the filled area to achieve the desired surface finish.

The Extra-Fast-Setting epoxy filled with carbon spheres performs adequately for filling fastener holes and small surface flaws, but because of its higher than desired coefficient of thermal expansion should not be used on critical aerodynamic surfaces.

Super Metal has the potential for wide usage on cryogenic wind tunnel models. It has the best thermal contraction rate match with cryogenic model structural materials, adequate shear strength, and can provide a good surface finish. A full endorsement is not given at this time due to incomplete evaluation.

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