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INITIAL INVESTIGATION OF
CRYOGENIC WIND TUNNEL MODEL
FILLER MATERIALS

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BY

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SUMMARY

Various filler materials are being investigated for applicability to cryogenic wind tunnel models. The filler materials are commonly used to fill surface flaws, instrumentation grooves and fastener holes in aerodynamic surfaces. More stringent surface quality requirements and the more demanding test environment encountered in cryogenic wind tunnels eliminate from consideration filler materials such as polyester resins, plasters and waxes which are used on conventional wind tunnel models.

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 metals. 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 are acceptable for usage with cryogenic wind tunnel model components.

INTRODUCTION

Smooth, continuous aerodynamic surfaces are required on wind tunnel models to minimize surface induced flow disturbances. The surface quality requirements are more stringent for models to be tested in the National Transonic Facility than for conventional wind tunnel models due to the higher

Reynolds Number capabilities of the new cryogenic tunnel. Acceptable surfaces have been achieved on conventional wind tunnel models by filling gaps, fastener holes and flaws with waxes, plasters and/or polyester resins. These filler materials are unsuitable for NTF models due to low temperature embrittlement and contour instability of filled areas because of the greater contraction of filler materials versus model structural material as temperatures are lowered.

A program was initiated to identify or develop filler materials which will perform satisfactorily in the NTF test environment. The filler materials are to satisfy the following criteria:

1. Filler material must maintain adherence to parent material throughout exposure to NTF test environment.
2. Filler material must provide a stable, high quality surface.
3. Filler material must be easily applied and hand worked.
4. Filler material should be easily removed, easily applied to cold surfaces (40°F) and be rapid curing (< 20 minutes).

Activities to date have focused primarily on criteria one and two. Criteria three and four addresses minimizing tunnel down time for model modifications.

Two filler material systems have been identified which satisfy the first three criteria for usage with aluminum components. Results to date indicate that, with proper tailoring, the systems will perform satisfactorily with all potential cryogenic model materials. Another filler material, which has undergone limited testing, apparently satisfies all criteria for usage with aluminum components, and should, with proper tailoring, be acceptable for limited usage with the remaining cryogenic model materials.

TEST PROCEDURE

Three specimen configurations are being utilized to simulate usage on wind tunnel model surfaces. One configuration (fig. 1) used for filler material screening consists of a small flat metal plate which contains bored holes and surface grooves representing fastener holes and instrumentation routing grooves. A more sophisticated specimen (fig. 2), used for filler material verification, consists of a flat metal plate with a surface groove, two cover plates with varying perimeter gaps, bored holes and fasteners. These specimens are filled with candidate filler materials and hand finished. The surface contour and roughness is then measured with a profilometer. The specimens are subjected to thermal cycling from 140° to -300°F for five cycles and then remeasured and examined for bond failure or surface cracking. Each configuration is available in each primary cryogenic model material class (i.e. aluminum, austenitic steel, ferritic steel and martensitic steel).

A third configuration (fig. 3) simulates a tapered wing with surface grooves. Orifice tubing is secured in the grooves and covered with a filler material. After hand finishing, the specimen is measured and subjected to thermal cycling and remeasured, following the procedures used for the flat plate specimens. Following the successful completion of the thermal cycling, the specimen is placed in a cryostat (approximately -300°F) and subjected to load cycling from no load to full load for five thousand cycles. The initial load of 50 pounds creates a specimen surface stress of twelve thousand pounds per square inch. If no failures are found, the load is increased in fifty pound increments until a maximum load of two hundred pounds (forty eight thousand pounds per square inch) is reached. This configuration is available only in a martensitic steel.

Concurrent with the flat plate specimens, testing is being conducted to determine the coefficient of thermal expansion of the filler materials. Molded 1/4 inch diameter x 3 inches long specimens of filler materials are compared to various cryogenic model material standards using a laser interferometer (fig. 4). This noncontact system permits high accuracy measurements over the entire temperature spectrum of the NTF.

FILLER MATERIALS

Commercial metal filled epoxy products have been used successfully on conventional wind tunnel models and, to a limited degree, on models for Langley Research Center's 0.3 Meter Transonic Cryogenic Tunnel. Two products (Devcon "F" and Devcon "ST") representative of the commercially available metal-filled epoxies, were examined to determine if their usage in the NTF would have to be limited because of problems related to the expected high coefficients of thermal expansion. Each of the two products tested consisted of eighty percent by weight metal powder (one utilizes aluminum, the other utilizes steel).

Previous work at LaRC, during the Pathfinder I design program, identified a filler material composed of a structural adhesive epoxy (EA-934) modified with the addition of two parts aluminum powder by weight to each part epoxy (ref. 1). Subsequent studies at LaRC and in private industry have pointed out that, while having good adhesion and offering a reasonable surface finish, its coefficient of thermal expansion is greater than cryogenic model materials, which will result in depressions in the filled areas at low temperature (refs. 2, 3, & 4). Two formulations of this structural adhesive EA-934 (containing asbestos) and EA-934NA (containing a substitute for asbestos) were reviewed in the testing and served as the basis for further modification of structural adhesives.

Another structural adhesive epoxy, EA-9309, was included in the program because of its lower viscosity and resulting potential for higher metal to epoxy ratios. Austenitic and martensitic steel powders were added to the structural adhesives in the same ratios by volume as had been used for the aluminum modified adhesives. Finally, carbon spheres and talc have been added to the adhesives in an effort to reduce further the coefficient of thermal expansion and increase the workability.

A five-minute-epoxy (modified in the same fashion as the structural adhesives) has been included in the testing program. The modified epoxy (Hardman "Extra Fast Setting") has been tested primarily for application to fastener holes requiring frequent removal.

A room temperature curing polyimide adhesive ("Super Metal") has been added to the program on the basis of favorable comments from the Norfolk Naval Shipyard. The Super Metal adhesive contains iron and talc particles as fillers, and has an advertised thermal expansion coefficient nearly matching that of the aluminum alloys. The adhesive has been tested with and without the addition of carbon spheres.

RESULTS AND DISCUSSION

Testing of the flat plate specimens indicate that metal-filled adhesives are not capable of fulfilling the major requirements for use with NTF models, whereas certain carbon-filled adhesives do satisfy the major requirements of maintaining adherence to the parent metal and providing a stable surface.

The typical metal-filled adhesive exhibited bond line failure and consequent differential movement relative to the plate (fig. 5). The three structural adhesive epoxies filled with metal powders were mated with aluminum, austenitic and martensitic steel flat plates and tested. The austenitic steel-filled EA9309 applied to an austenitic steel flat plate is the only metal-filled system tested which satisfied the two major criteria. The aluminum-filled EA-934 and EA-934NA did maintain adherence to an aluminum plate but both exhibited some shrinkage. All metal-filled systems could be polished to a 30-40 RMS finish.

The carbon modified adhesives performed better than the metal filled systems with respect to maintaining adherence to the plate and providing a stable surface. The carbon filled adhesives were tested in combination with aluminum and ferritic steel flat plates. The carbon filled EA-934 formulations showed movement relative to an aluminum plate which apparently was caused by particle saturation of the resin preventing sufficient bonding to the plate. The carbon filled Extra-Fast-Setting epoxy failed when applied to a ferritric steel plate but performed satisfactorily with aluminum plates. EA-9309 and Super Metal performed satisfactorily with aluminum and ferritic steel plates. Surface finish for the carbon filled systems were in the 50-80 RMS range due to the large particle size (190 microns).

An aluminum plate was tested using talc filled EA 9309 and Extra-Fast-Setting epoxy. Both met the major requirements and provided a finish comparable to the metal filled systems.

Super Metal was applied without modification to an aluminum flat plate and performed exceptionally well. The surface finish was marginally better than the metal filled systems and was easier to hand work. Results of the flat plate specimen tests are shown in table 1.

Lacquer glazing compounds were used successfully to fill voids and improve the surface finish in all the systems. Spray lacquer was used to improve the surface finish to the 10-16 RMS range, but flaked off of several specimens during thermal cycling.

The coefficient of thermal expansion measurements verified the expected high values of the metal filled epoxies. Additionally, the polyimide adhesive was found to match aluminum alloys without any modification. Additions of carbon particles (190 micron spheres) to EA 9309 in a 1:2 resin to carbon ratio also resulted in a coefficient match with aluminum. Greater concentrations of carbon in EA 9309 did not result in lower coefficients. Smaller particle size spheres (100 micron spheres) did not lower the coefficient as efficiently as the larger spheres and, because of the increased surface area, led to a much dryer system. An addition of carbon particles to Super Metal in a 1:1 ratio resulted in a coefficient matching that of austenitic steels. The other adhesive systems became saturated with the carbon particles before the coefficient of aluminum alloys could be reached. The results of the laser interferometer tests are shown graphically in figure 6a through 6e. The coefficients of talc modified adhesives could not be determined because of moisture absorption and consequent specimen length instability.

The tapered wing specimen was tested using EA 9309 filled with carbon particles (190 micron spheres) in a 1:2 resin to carbon ratio. Thermal cycling and dynamic cycling in a cryostat for five thousand cycles each at stress levels of twelve, twenty-four, thirty-six and forty-eight thousand pounds per square inch caused no bond line failures, cracking, or surface movement.

CONCLUDING REMARKS

Carbon-filled EA 9309 has been tested extensively with aluminum, ferritic and martensitic steel specimens without any evidence of bond line shear or surface instability. The laser interferometer tests indicate that a carbon to resin ratio of 2:1 matches the aluminum alloy coefficients of thermal expansion. Higher carbon ratios offered no significant reduction in the coefficient and should not be used because of potential bond strength reductions.

Super Metal matches aluminum alloys without modification and, with modest additions of carbon, should be suitable for most cryogenic wind tunnel model application. More testing is recommended before carbon modified Super Metal is used for NTF models.

The Extra-Fast-Setting epoxy with carbon additions appears to be most suitable for fastener hole filling during model modifications. Care should be exercised to avoid use of this system on critical aerodynamic surfaces as the contraction differential between the system and the parent metal will cause surface dimpling.

Testing of the filler materials is continuing in an effort to provide better matching with coefficients of thermal expansion of the various steels. Lap shear strengths for the various systems and the effects of varying filler concentration are also being examined.

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TABLE 1: RESULTS OF VARIOUS FILLER SYSTEM/SUBSTRATE COMBINATIONS

FILLER SYSTEM	SUBSTRATE			
		STEELS		
ADHESIVE/FILLER	ALUMINUM	AUSTENITIC	FERRITIC	MARTENSITIC
EA 934/Alum.	(1:2)a	(1:2)b,c,d		(1:2)c,d (1:2)*c,d
EA 934/Aus. Stl.		(1:6)c		
EA 934/Mar. Stl.				(1:2)a,c,d (1:2)*c,d
EA 934/Carbon	(1:1)c,d			
EA 934NA/Alum.	(1:2)a	(1:2)b,c,d		
EA 934NA/Aus. Stl.		(1:6)c		
EA 934NA/Carbon	(1:1)c,d			
EA 9309/Alum.	(1:2)b,c,d			(1:2)c,d
EA 9309/Aus. Stl.		(1:6)OK		
EA 9309/Mar. Stl.	(1:2)b,c,d			(1:2)c,d
EA 9309/Carbon	(1:1)OK (1:2)OK		(1:2)OK	(1:2)**OK
EA 9309/Talc	(1:2)OK			
Extra-Fast-Set./Aus. Stl.		(1:6)***e		
Extra-Fast-Set./Carbon	(1:1)***OK (1:2)OK		(1:2)c,d	
Extra-Fast-Set./Talc	(1:2)OK			
Super Metal	OK			
Super Metal/Carbon	(1:1)OK		(1:1)OK	

NOTE: (Resin to filler ratio by weight); OK...Acceptable
a...Shrinkage; b...Excessive Shrinkage; c...Bond Shear;
d... Filler Movement; e...Expansion

*Inadequate Substrate Preparation
**Dynamic Specimen
***Fastener Holes Only

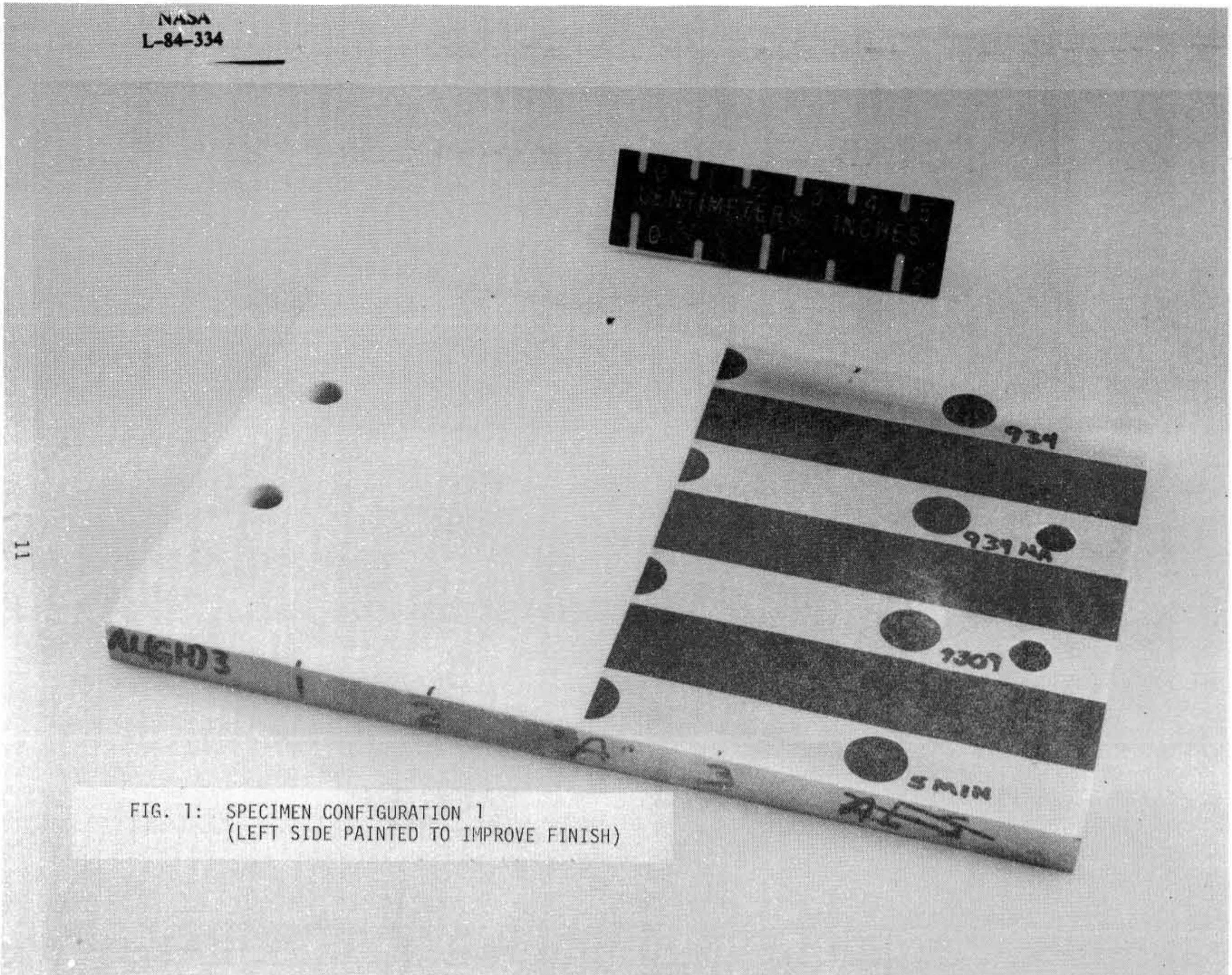


FIG. 1: SPECIMEN CONFIGURATION 1
(LEFT SIDE PAINTED TO IMPROVE FINISH)

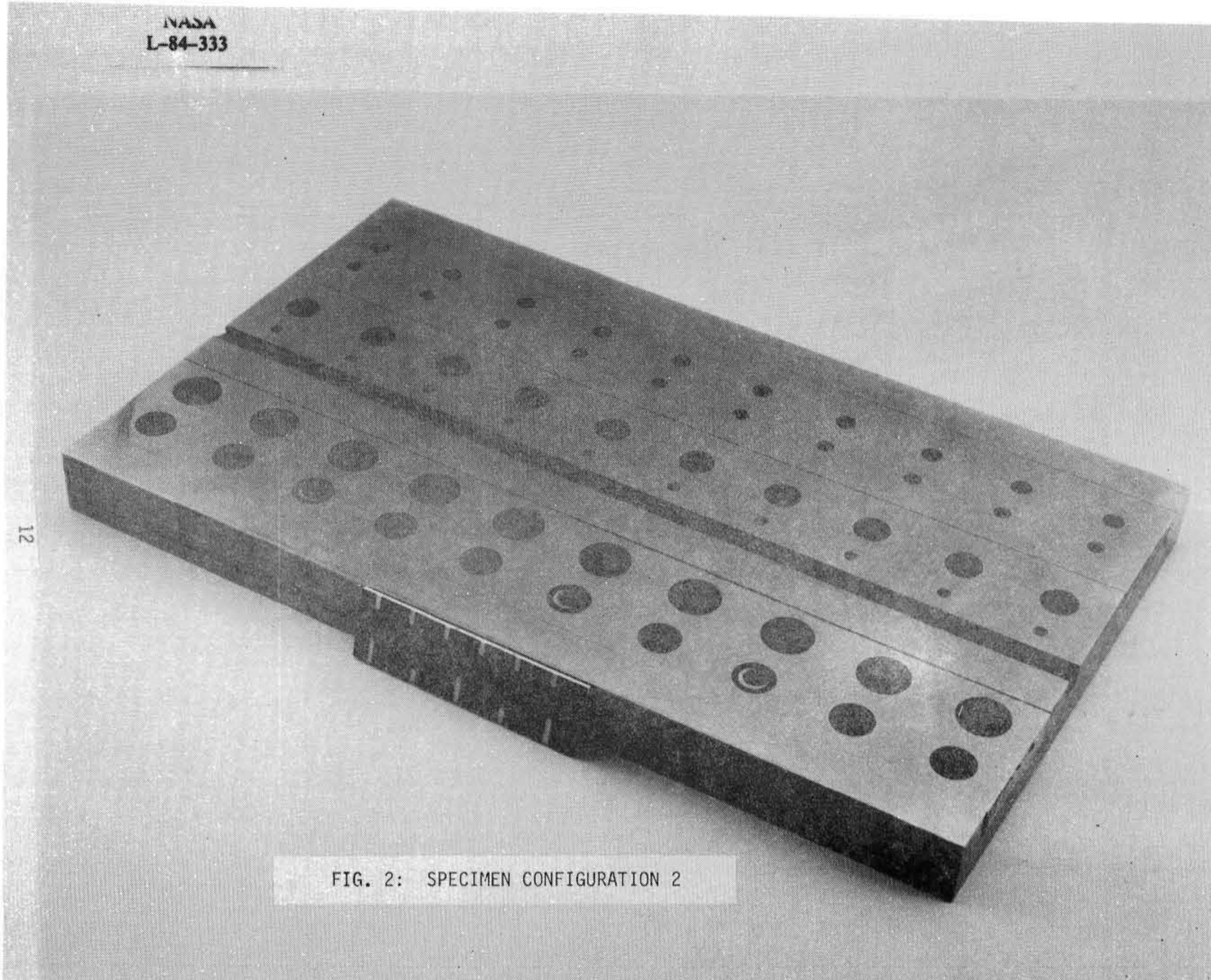


FIG. 2: SPECIMEN CONFIGURATION 2

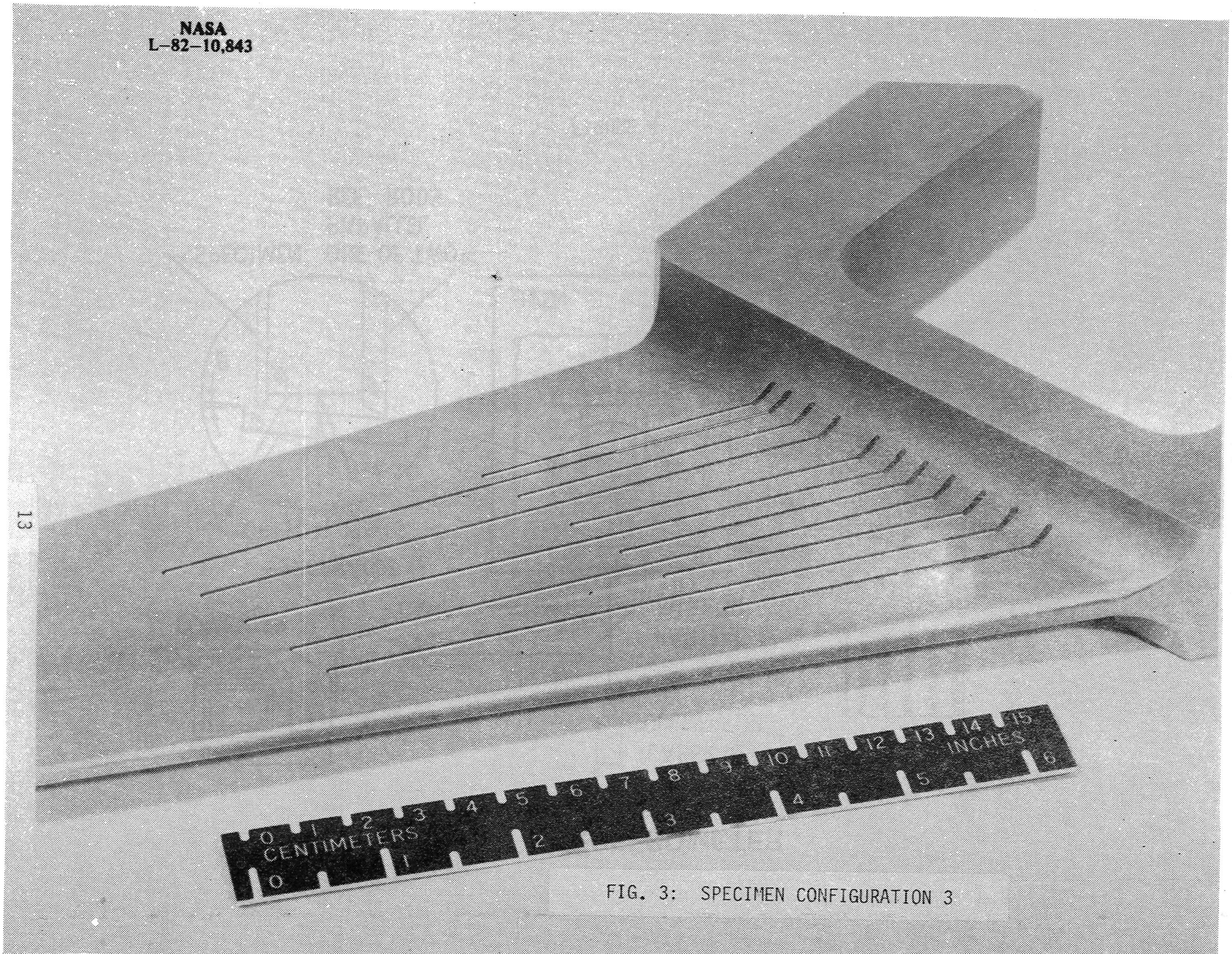
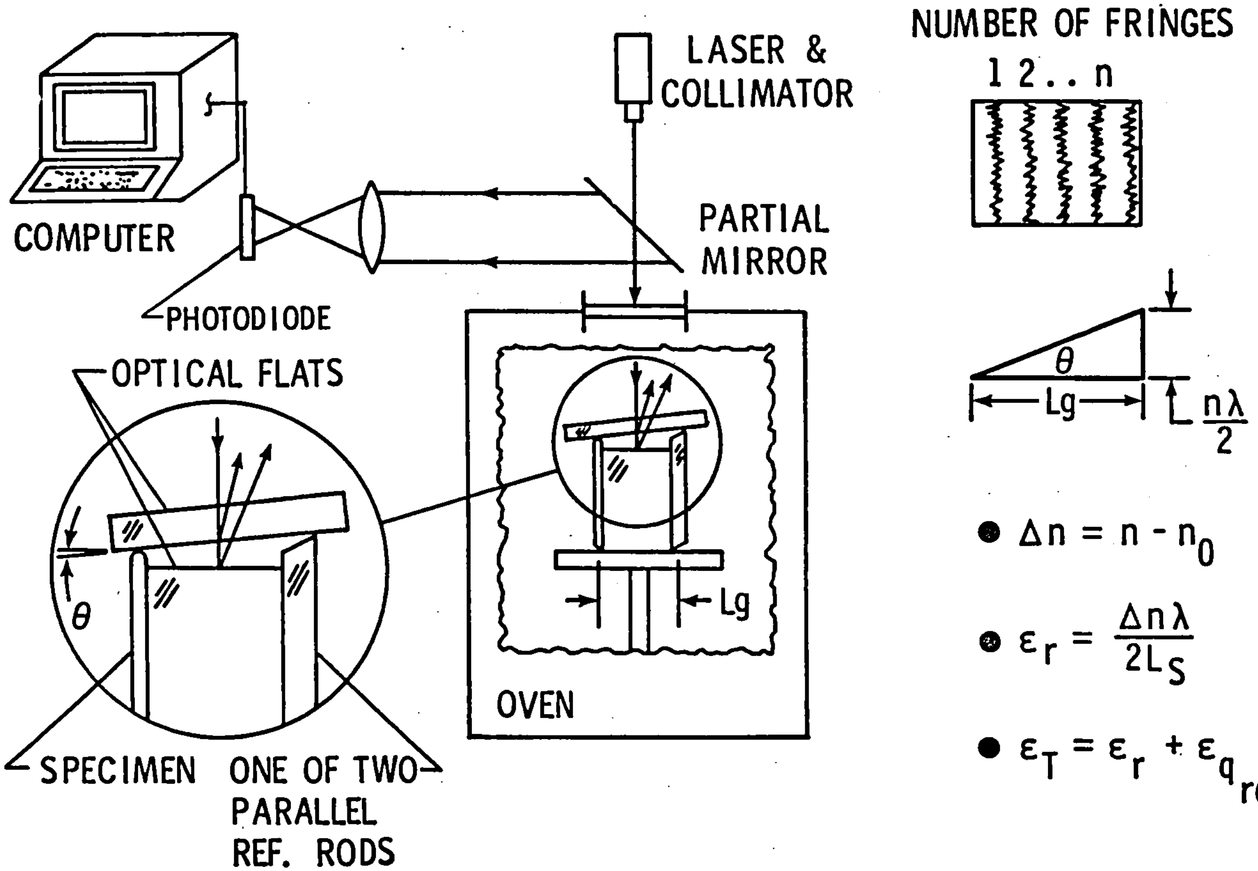


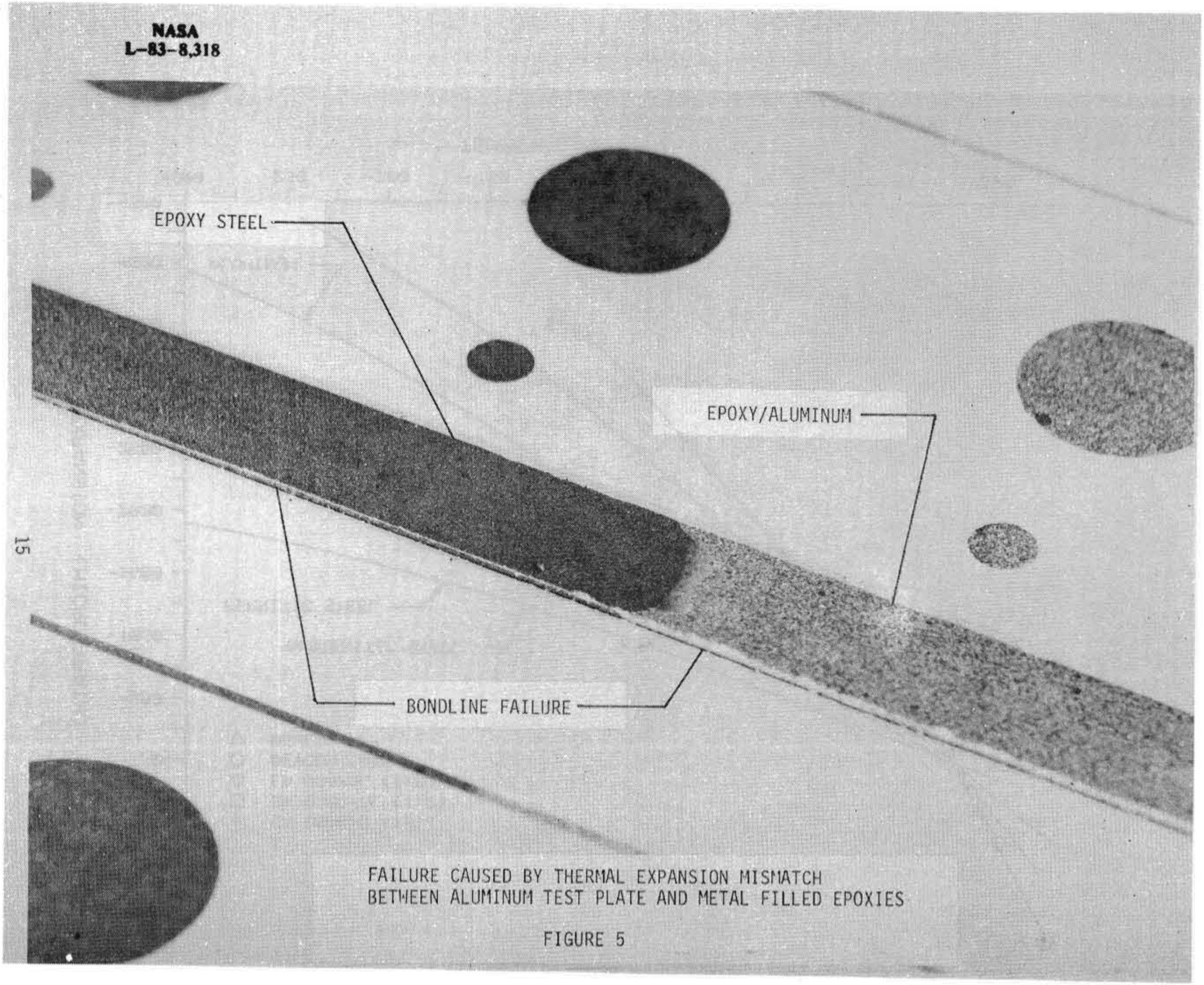
FIG. 3: SPECIMEN CONFIGURATION 3

PRIEST INTERFEROMETER



- $\Delta n = n - n_0$
- $\varepsilon_r = \frac{\Delta n \lambda}{2L_S}$
- $\varepsilon_T = \varepsilon_r + \varepsilon_{q_{ref\ rod}}$

FIGURE 4



FAILURE CAUSED BY THERMAL EXPANSION MISMATCH
BETWEEN ALUMINUM TEST PLATE AND METAL FILLED EPOXIES

FIGURE 5

THERMAL EXPANSION VERSUS TEMPERATURE
OF VARIOUS METAL FILLED ADHESIVES

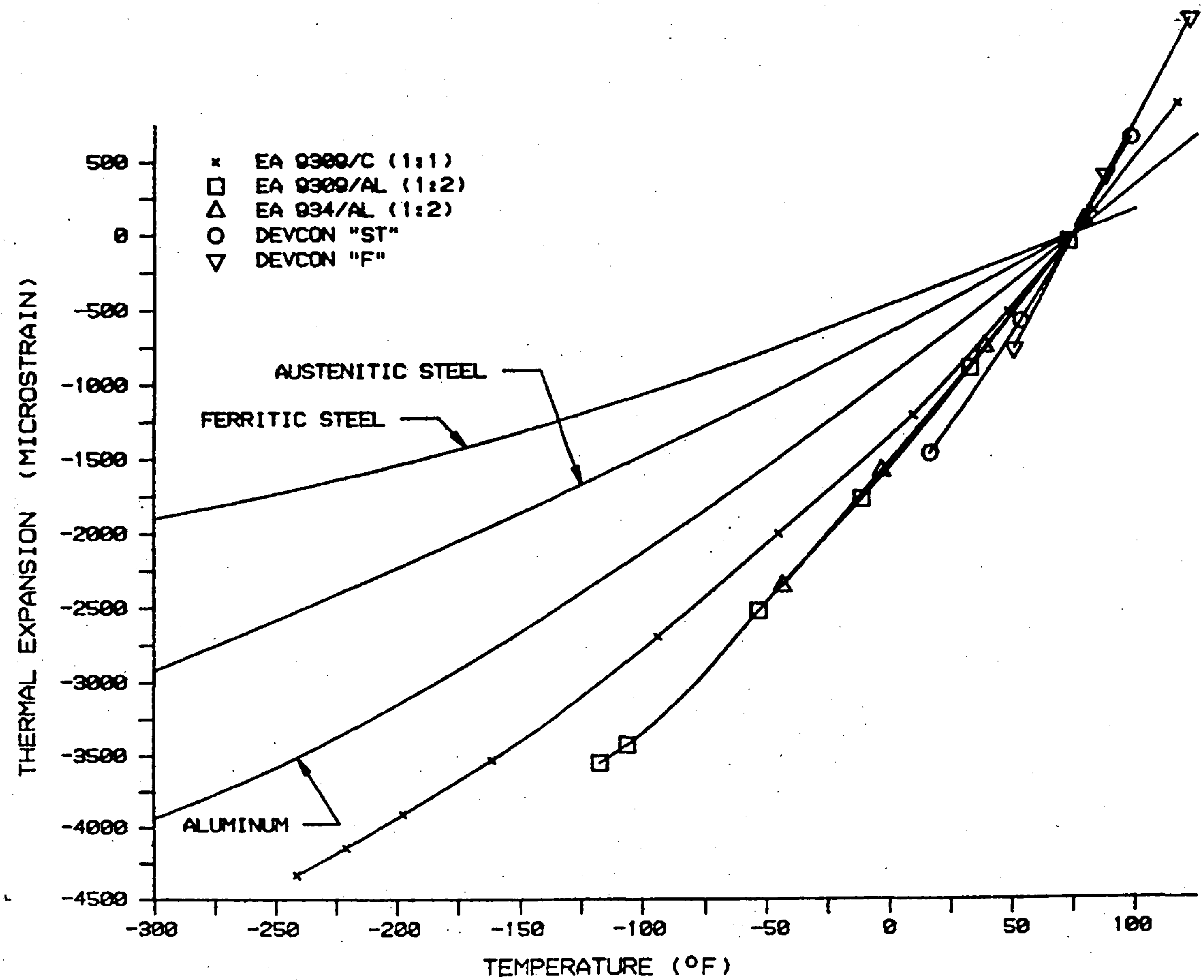


FIG. 6a

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

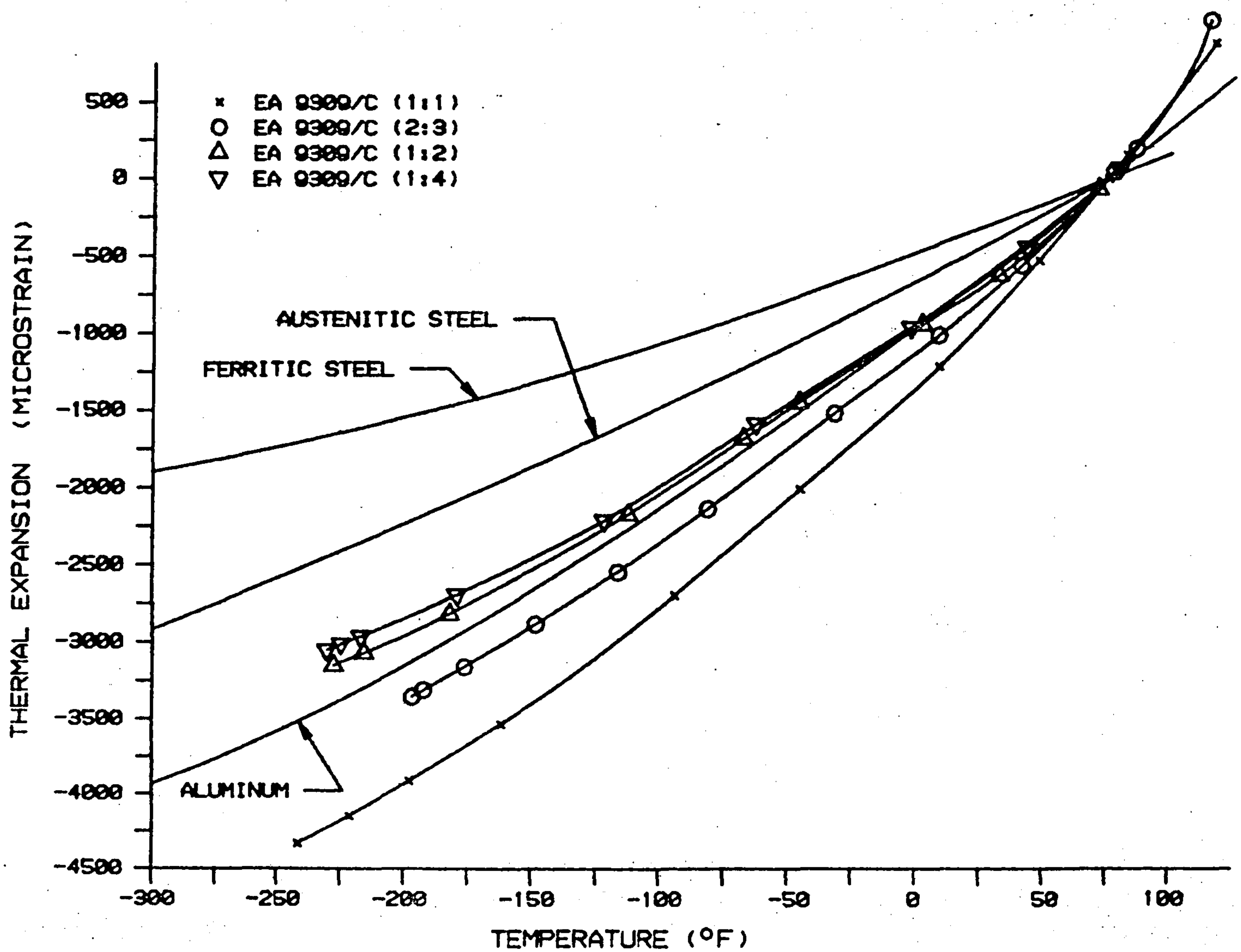


FIG. 6b

THERMAL EXPANSION VERSUS TEMPERATURE
COMPARISON OF EFFECTIVENESS
OF TWO DIFFERENT GRAIN SIZES

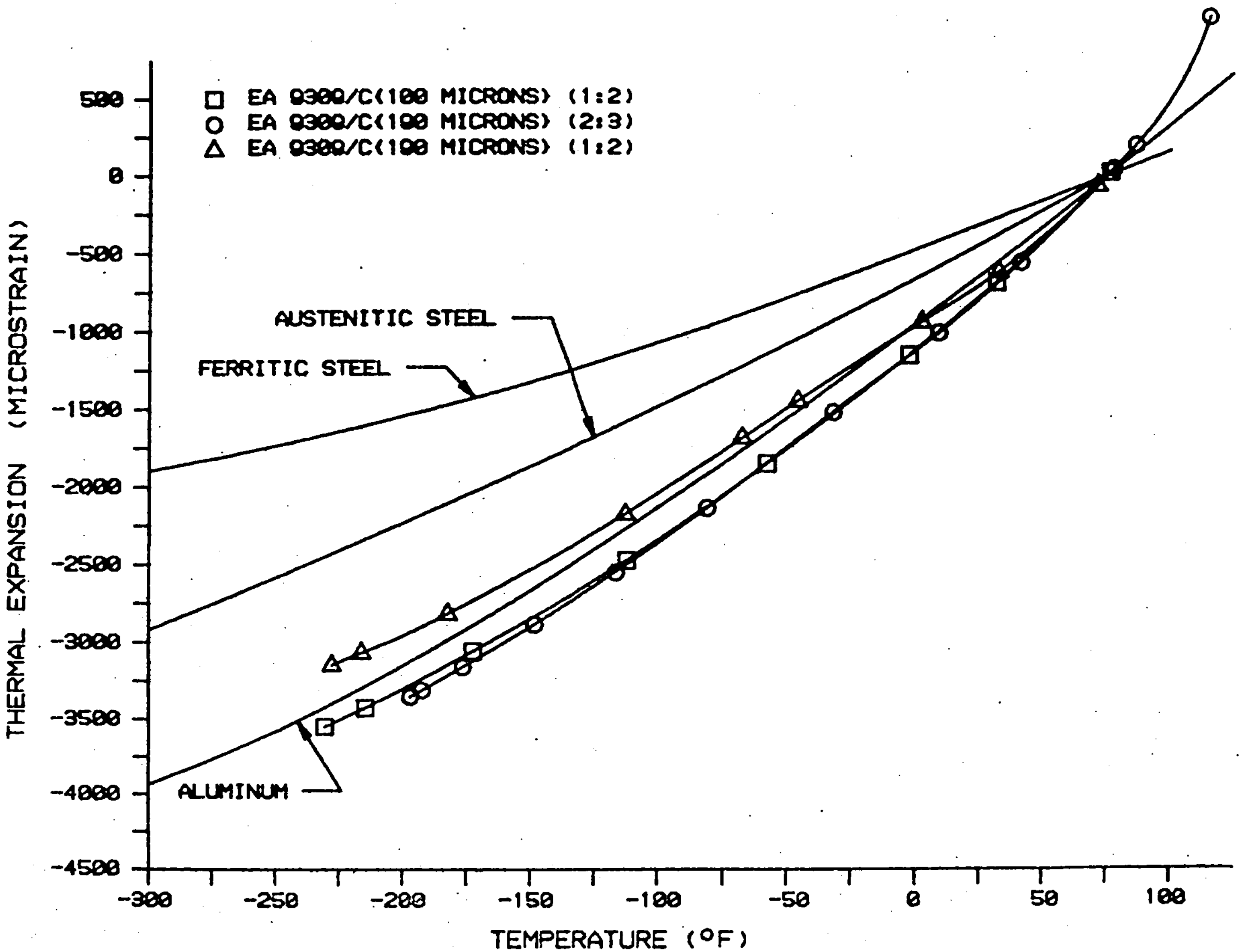


FIG. 6c

THERMAL EXPANSION VERSUS TEMPERATURE
OF THREE CARBON FILLED ADHESIVES

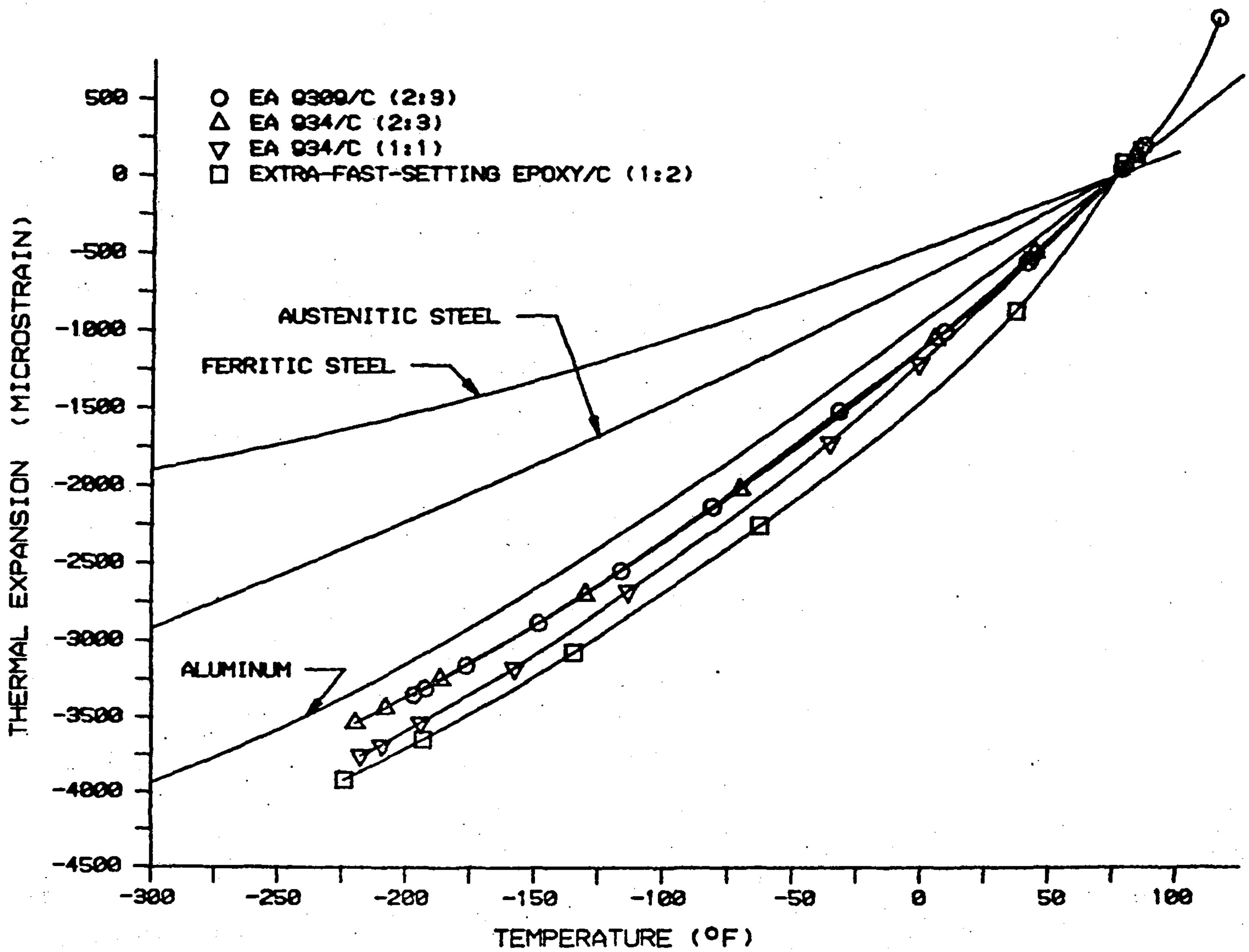


FIG. 6d

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

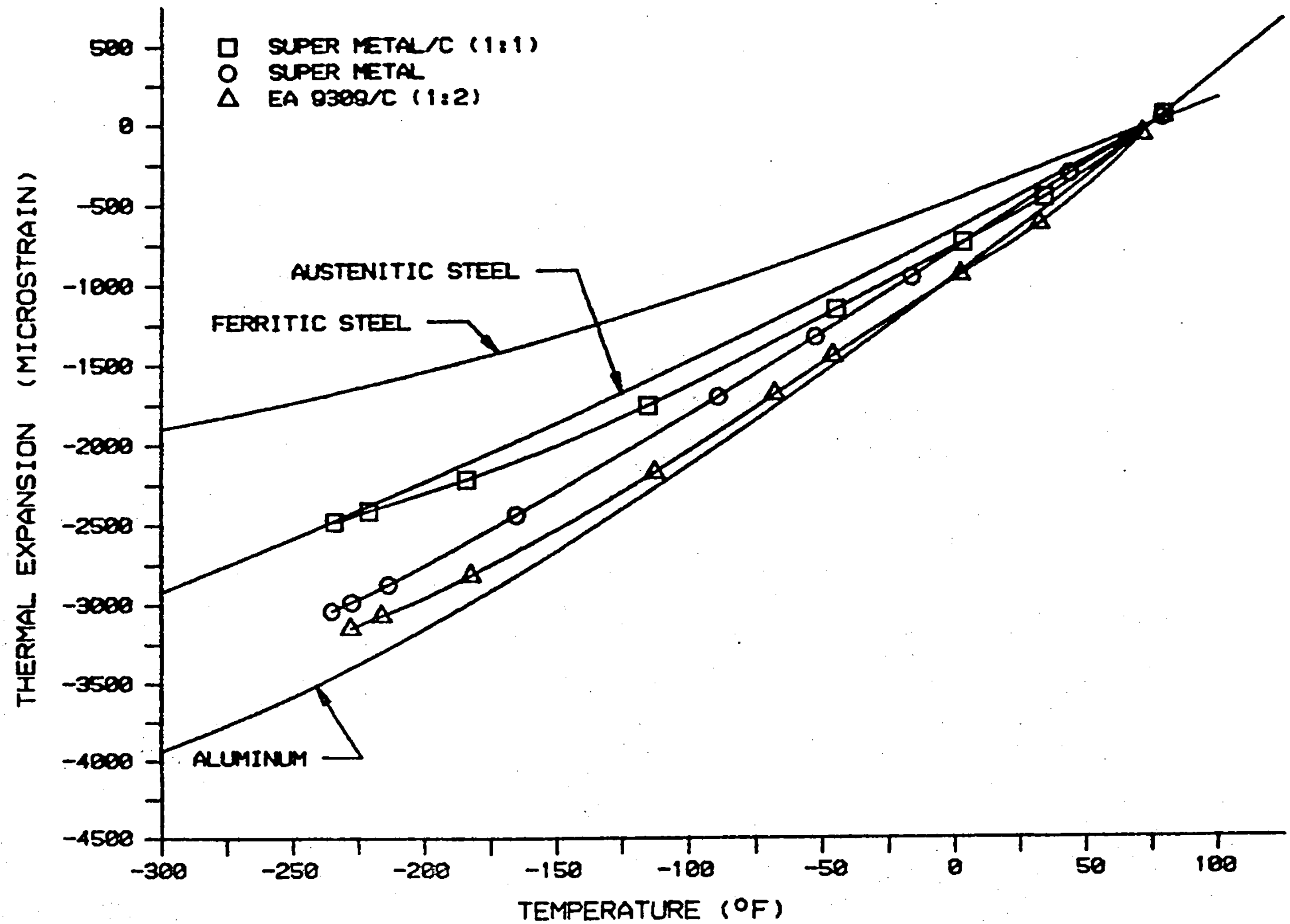


FIG. 6e

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15. Supplementary Notes

16. Abstract

Various filler materials are being investigated for applicability to cryogenic wind tunnel models. The filler materials will be used to fill surface grooves, holes and flaws. The severe test environment of cryogenic models precludes usage of filler materials used on conventional wind tunnel models.

Coefficients of thermal expansion, finishing characteristics, adhesion and stability of several candidate filler materials have been examined. Promising filler materials are identified.

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