THE EFFECT OF GAS ON THE MECHANICAL PROPERTIES AND PROCESSING OF ALUMINUM BRONZES

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SUMMARY, OBJECTIVES

In previous papers (1,2) the development of a sensitive test to evaluate the gas content of aluminum bronze and the effects of melt and mold variables upon the gas content were reported. Following this work a number of additional variables seemed to warrant investigation and these constituted the objectives of this year's work:

(1) The susceptibility of the full range of compositions of aluminum bronze to gas pickup.

(2) The effect of size of gas furnace on gas pickup.

(3) The effect of purging with oxygen as contrasted with nitrogen.

(4) Further evaluation of the effects of the levels of gas content upon mechanical properties in different section thicknesses.

(5) Correlation of microstructure with mechanical properties.

The data indicate:

(1) The susceptibility to gas pickup over the composition range of aluminum bronzes varies from a minimum of 70 mm for 9D (955) to 120 mm for 9A (952) alloy.

(2) Variation in gas pickup is related to surface area and volume of furnace.

(3) Oxygen is a more effective purging gas than nitrogen and aluminum loss is not excessive.

(4) The effect of dissolved gas is pronounced in heavy sections and relatively minor in light sections.

(5) The low elongation encountered in sound heavy sections of aluminum bronze is due to a coarse platelike eutectoid structure which gives a brittle fracture as shown by scanning electron micrographs.

PROCEDURE

The procedures have been described in previous papers and only important features will be reviewed here. Heats were made either in a 200 lb capacity, 3000 cycle induction lift coil furnace with clay graphite crucibles or in a 30 lb gas fired furnace with a clay graphite crucible as denoted in the text or figures. To evaluate the effect of furnace size, a 200 lb capacity gas fired furnace was used in addition.

Melts were made from secondary ingot or a mixture of ingot and carefully segregated material from previous heats.

Molds were made of silica sand and a cold set binder following standard techniques. Chills were of graphite.

The gas pressure of the melt was evaluated in equipment developed and described previously. The gas level is determined by dipping a sample of the melt with a preheated porcelain crucible, placing the crucible quickly in a controlled low pressure chamber and determining the pressure at which a bubble just forms but does not break the solidifying metal surface. At a gas level of 100 mm, for example, the reproducibility is ±5%.

DATA

(1) Susceptibility of aluminum bronze of various compositions to gas pickup. Melts of aluminum bronzes 9A through 9D (952-955) were melted in the 30 lb gas furnace under equivalent conditions and the gas content was measured as a function of time, Fig. 1. The alloys show the same order of magnitude of gas pickup but the 5% nickel alloy exhibits the lowest value. In general, if the holding time at 2250°F is kept under 30 min. the gas levels of all alloys are comparable.

(2) Effect of furnace size. A 150 lb melt of virgin ingot of alloy 9C (954) was melted in a larger (200 lb) gas furnace for comparison with the data for the 30 lb furnace. The data of Fig. 2 show that the initial readings of gas content for the large furnace are higher but are influenced by the longer time necessary to bring the melt to 2250°F. The final plateaus are similar. The slightly lower value for the 200 lb furnace might be attributed to the lower surface area to weight ratio. The data reemphasize the desirability of reducing holding time to a minimum.

(3) Effect of purging with oxygen. Acting on the suggestions of D. Schmidt and others based on observations that oxygen was being used successfully for degassing in commercial practice, an evaluation was undertaken. The results of purging with oxygen and other gases are shown in Fig. 3. The purging with oxygen is more effective than with dry nitrogen and the change in aluminum was only from 10.39% Al to 10.11% Al. It is important to note that a purging time of only one minute was used and was quite effective. Use of oxygen for longer times (as customary with nitrogen) would of course lead to high aluminum loss.

(4) Effect of gas content on mechanical properties. Previous work (2) for 9C (954) indicated that the mechanical properties of light sections (1 in.) were relatively insensitive to gas content but that 3 and 6 in. Y blocks were sensitive. An added variable is that the whole range of properties in all cases is lower in heavy sections.

In this work additional heavy section castings of 9C (954) were poured at intermediate gas contents. The data for 3 in. Y blocks are given in Fig. 4 and for 6 in. Y blocks in Fig. 5. One apparent anomaly is the higher elongation in the 6 in. blocks at an intermediate gas content.

Additional data for lighter sections are shown in Figs. 6 and 7.

In an attempt to separate the effects of gas content and cooling rate on mechanical properties, a series of sound, gas free bars (in chilled 1 in. Y blocks) was produced. The gas pressure of the melt was less than 23 mm. The specimens were all heated to 1650°F for 1 hr and then cooled at different rates and tested with the following results:

Condition	Tensile strength, psi	Yield strength, 0.5 offset psi	% Elongation
Furnace cool	70,000	42,000	7
Air cool	98,000	35,000	23
Quenched in water and tempered 1200°F, 1 hr	105,000	44,000	19
Specification (min.)	75,000	30,000	12.5

The microstructure of the air cooled sample shows a fine eutectoid mixture of the ductile alpha phase and the hard γ_1 phase. By contrast the furnace cooled sample shows a coarse mixture with large plates of the brittle γ_1. The quenched sample shows tempered martensite.

(5) Correlation of microstructure with mechanical properties. A number of fractures from tensile specimens were examined under the SEM (Scanning Electron Microscope) and some typical structures are shown in Figs. 9-14.

Fig. 9 shows a typical shrinkage cavity with dendrites (3" Y, 50X).

Fig. 10 exhibits the effects of high gas and shrinkage giving smooth surfaces plus some dendrites.

Fig. 11 shows a sound area of Fig. 10 but away from the void. The fracture is brittle and platelike.

Fig. 12 shows a mixture of ductile cup and cone fractures with brittle fractures.

Figs. 13 and 14 show a nonmetallic inclusion which may contribute to low elongation.

CONCLUSIONS

(1) There is an appreciable difference in gas solubility in the four aluminum bronzes tested with alloy 9A (952) showing the highest gas level and alloy 9D (955) the lowest.

(2) The gas solubility in large and small furnaces appears to be similar and related to surface to volume area.

(3) Oxygen is an excellent purging gas and only a short blow is needed.

(4) The decrease in properties in heavy sections can be caused by shrinkage or gas cavities as well as by a coarse platelike γ_1 phase if the section is cooled slowly.

ACKNOWLEDGMENTS

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We are also grateful to R. Lavin and Sons for donation of raw materials and the chemical analyses.

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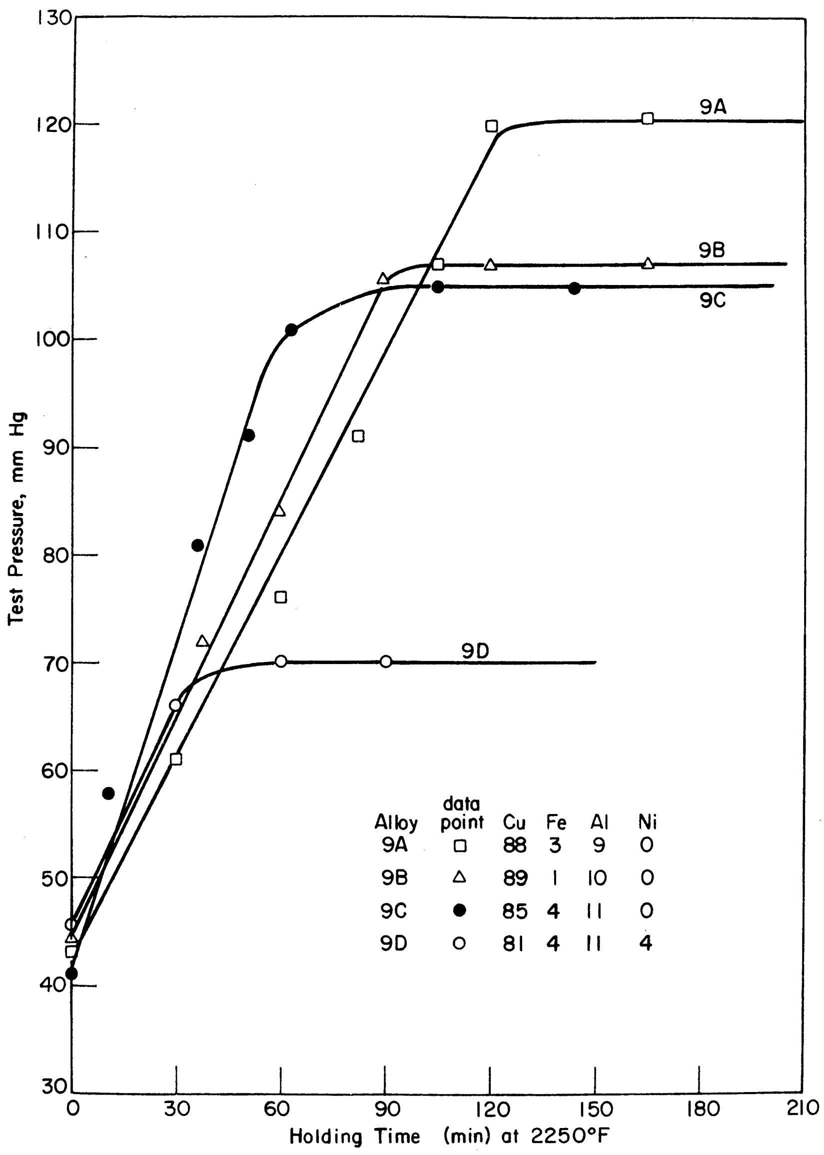


Figure 1. Sensitivity of the aluminum bronzes to gas pickup from the combustion products in a small (30 lb) gas furnace.

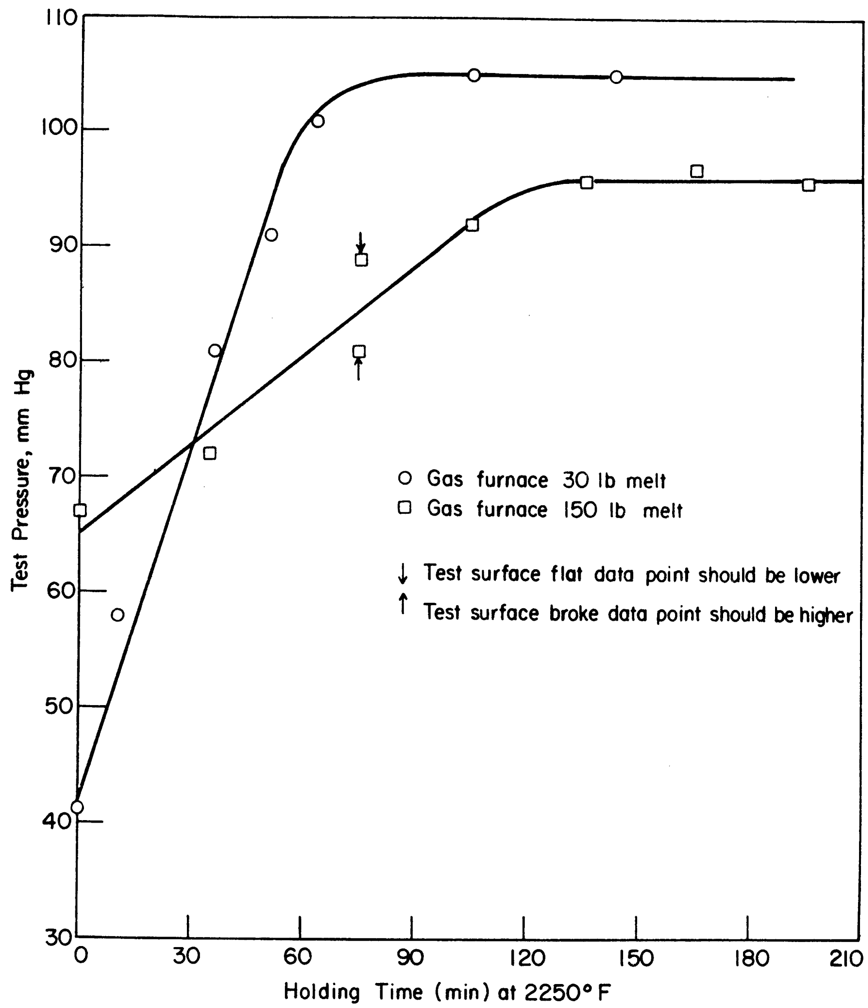


Figure 2. The effect of gas furnace size on the gas pickup in alloy 9C (954). The lower plateau in a larger furnace is due to a lower surface area exposed to the products of combustion.

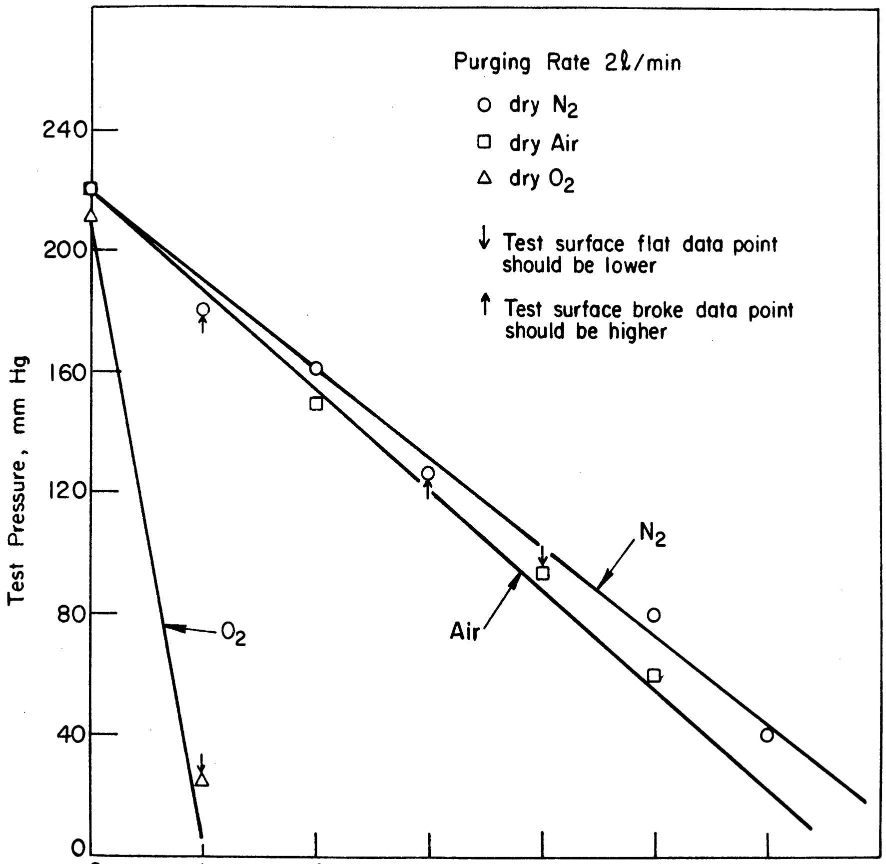


Figure 3. The effect of different purging gases on the rate of gas removal in alloy 9C (954) at 2250°F.

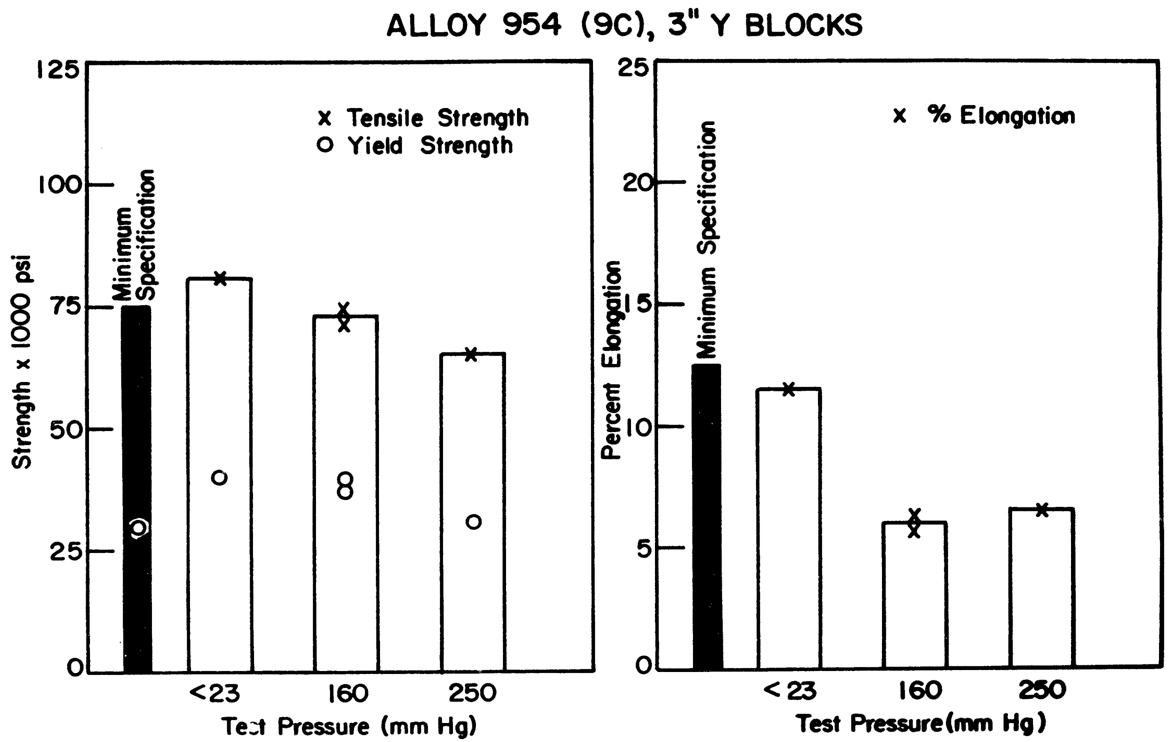


Figure 4. The effect of gas on the mechanical properties of alloy 9C (954) poured in 3" Y-block sections.

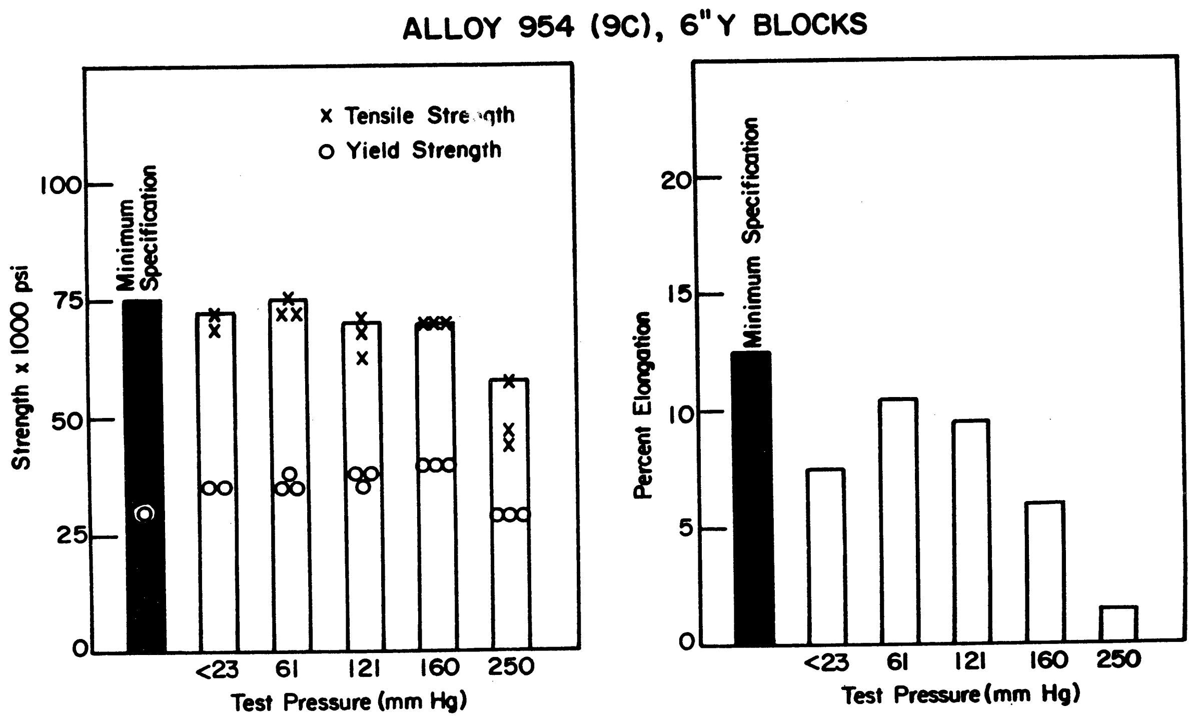


Figure 5. The effect of gas on the mechanical properties of alloy 9C (954) poured in 6" Y-block sections.

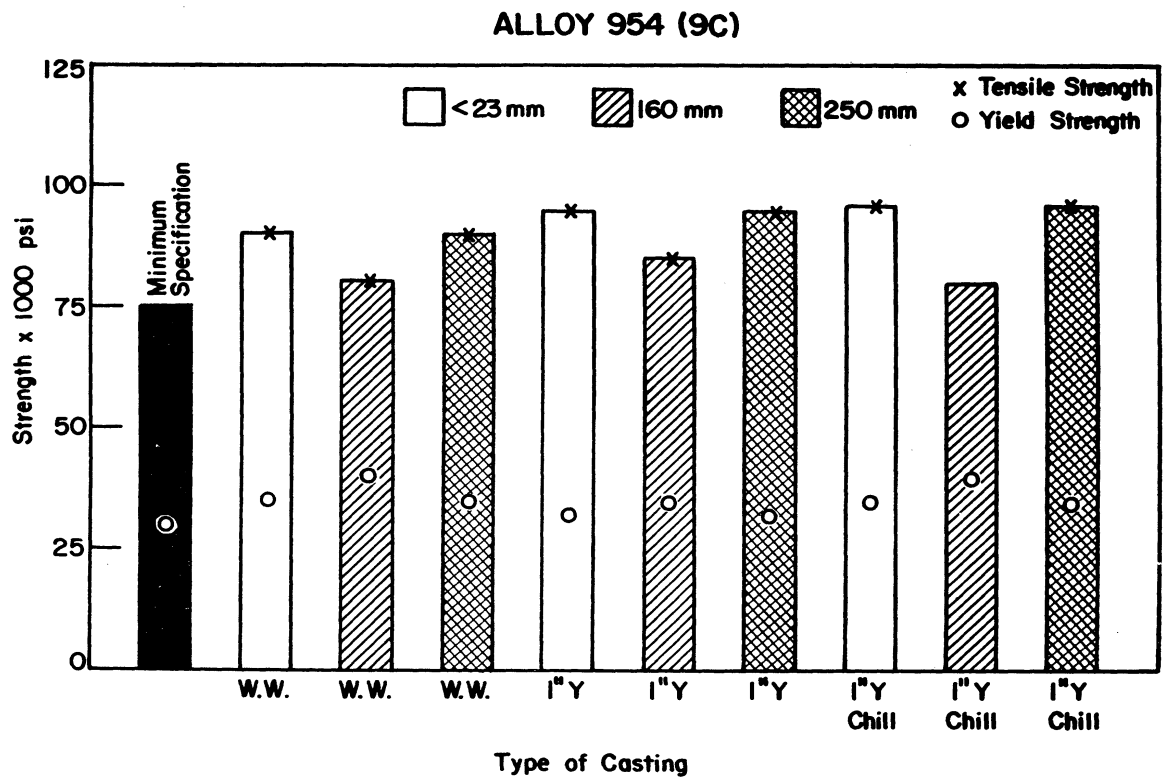


Figure 6. The effect of gas on the tensile and yield strengths of alloy 9C (954) poured in small sections.
W.W.: Web-Webbert; 1" Y: 1" Y-block; 1" Y chilled: bottom chilled 1" Y-block

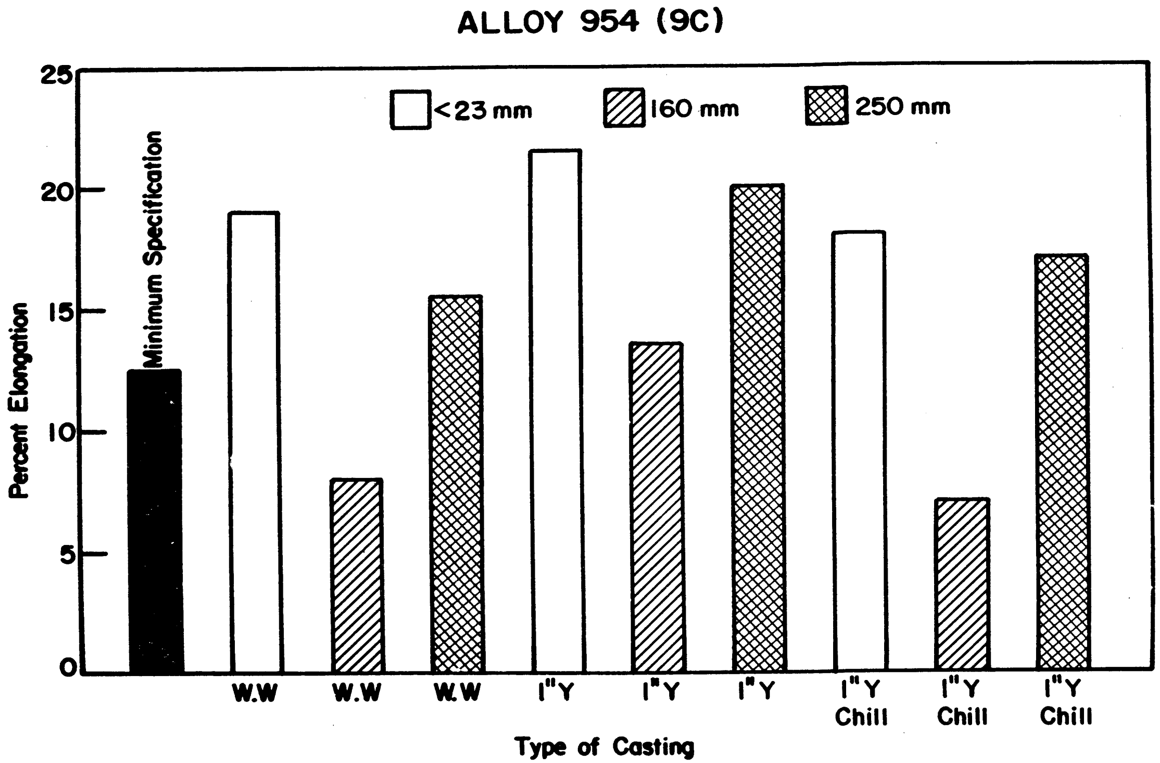
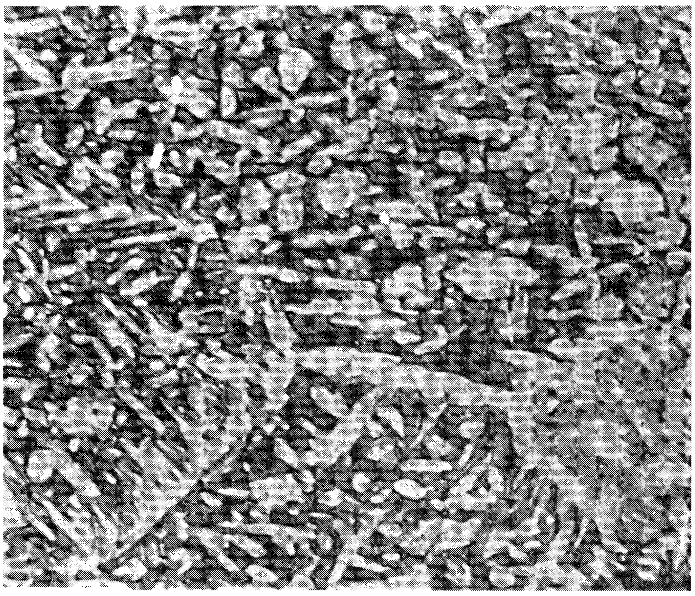
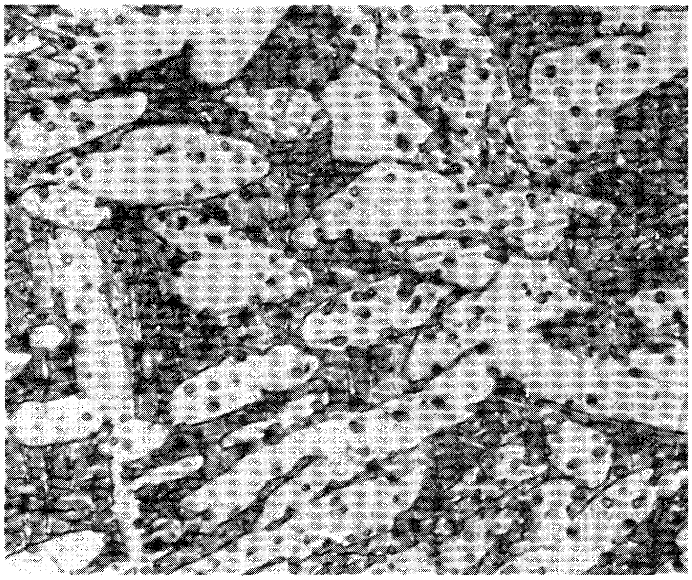


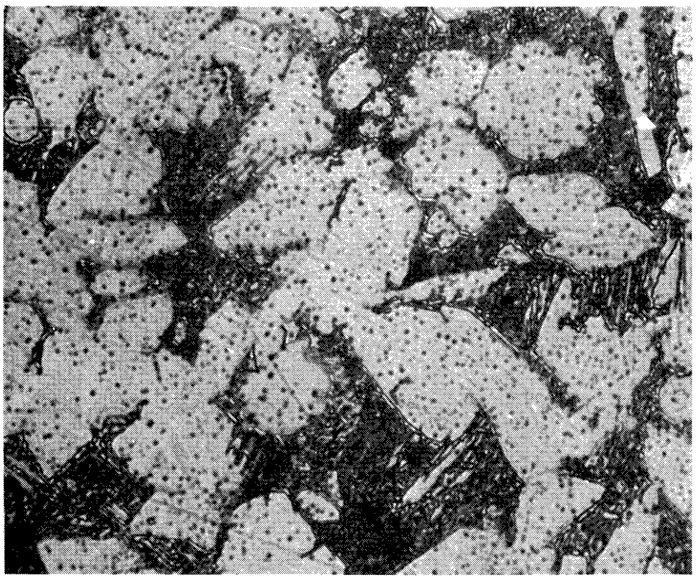
Figure 7. The effect of gas on the elongation of alloy 9C (954) poured in sections of approximately one inch.



Air cooled from 1650°F. 100X



Air cooled from 1650°F. 500X



Furnace cooled from 1650°F. 100X

Figure 8. Microstructures of aluminum bronze solution treated at 1650°F. Initial gas content <23 mm Hg.

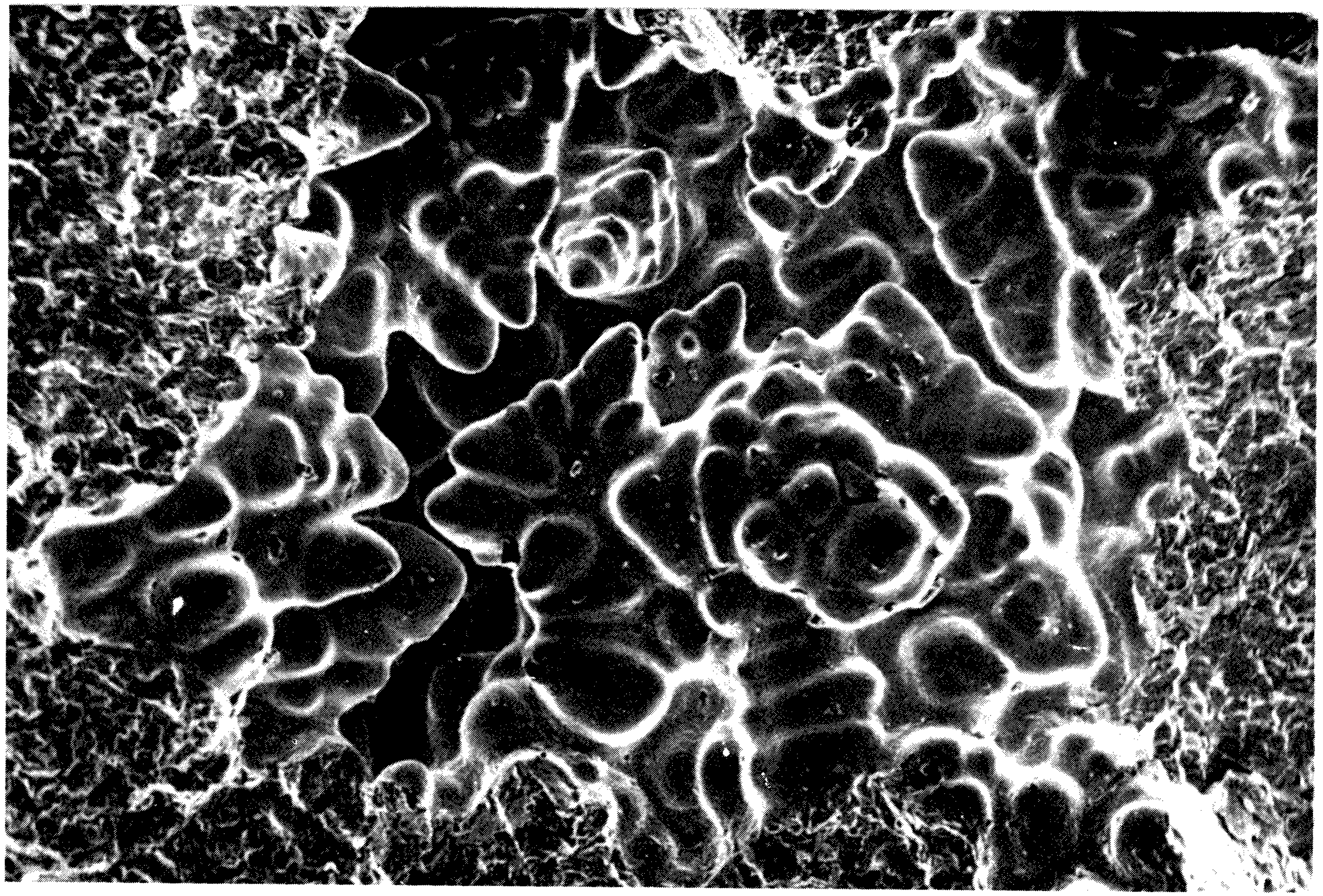


Figure 9. Shrinkage in the tensile fracture from a 3" Y-block section as shown by a scanning electron microscope. The gas content was 250 mm Hg and the elongation 7%. 50X.

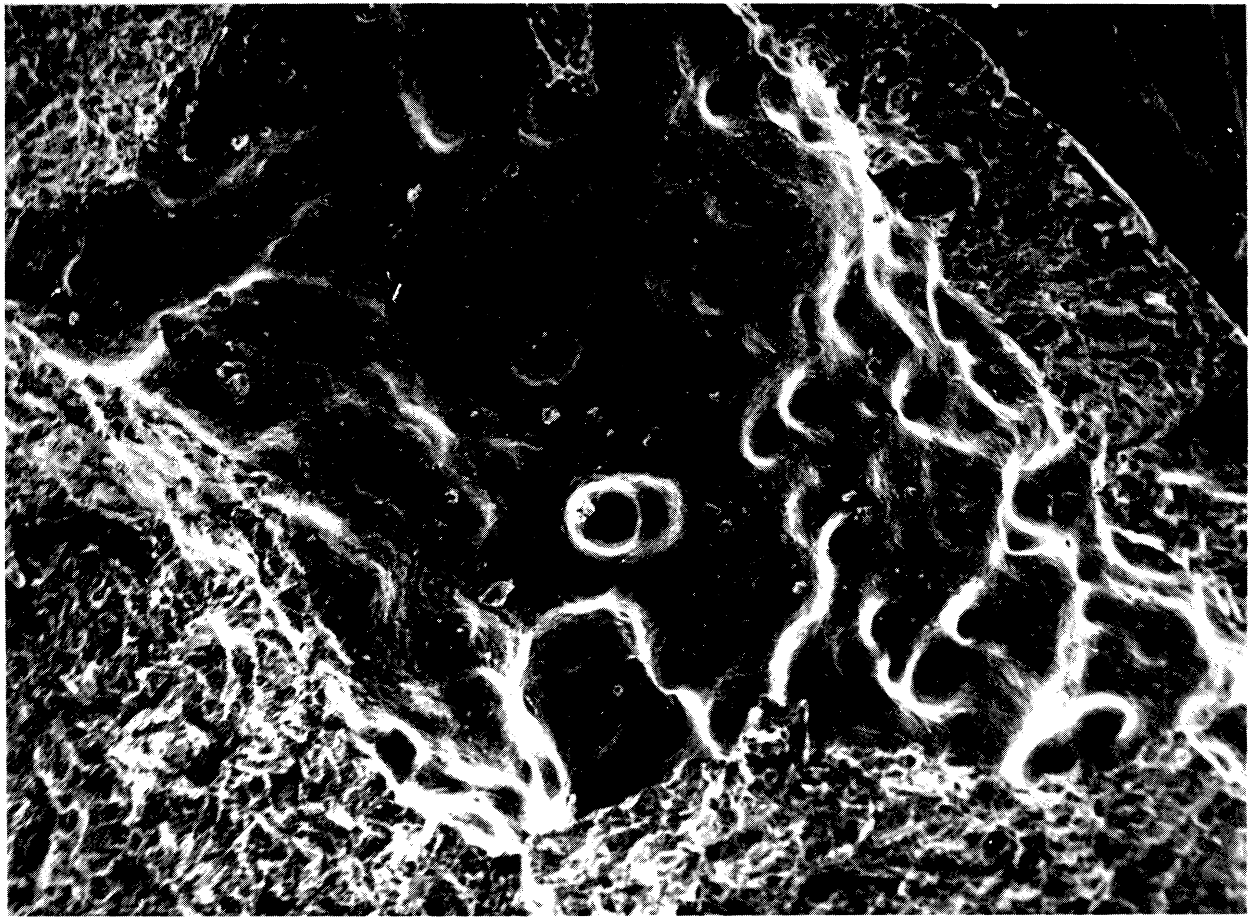


Figure 10. Gas porosity in a tensile fracture surface from a 6" Y block. The sample had a gas pressure equivalent of 250 mm Hg and an elongation of only 2%. 50X.

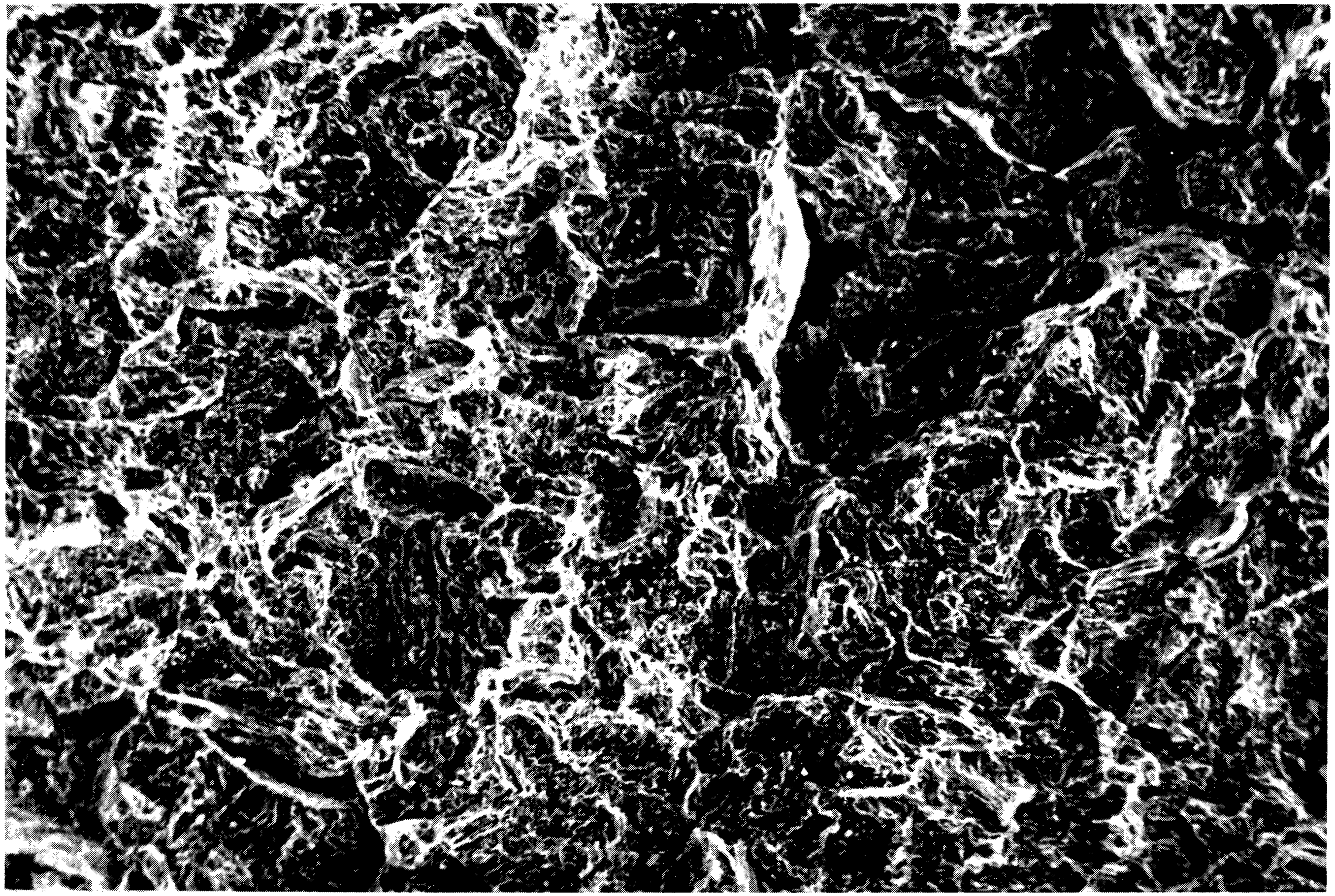


Figure 11. A higher magnification of a non-gassy area from the sample shown in Fig. 10. There is a complete lack of a shear (cup and cone) type of failure. 500X.

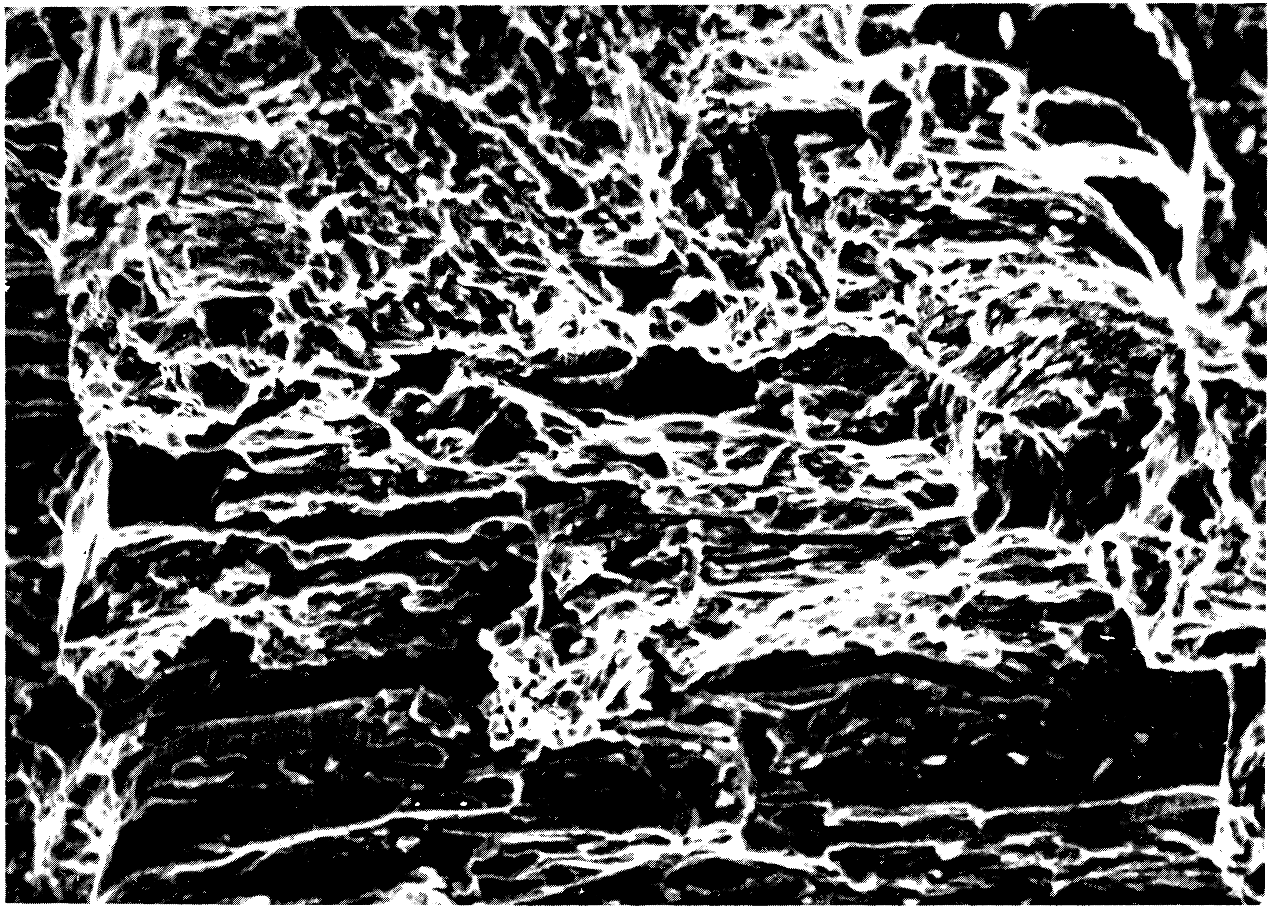


Figure 12. Scanning electron micrograph of a fracture from a 6" Y block which exhibited a gas test pressure of 61 mm Hg. The higher elongation of 11% provides a mixture of cleavage and shear failure. (Compare to Fig. 11). 500X.

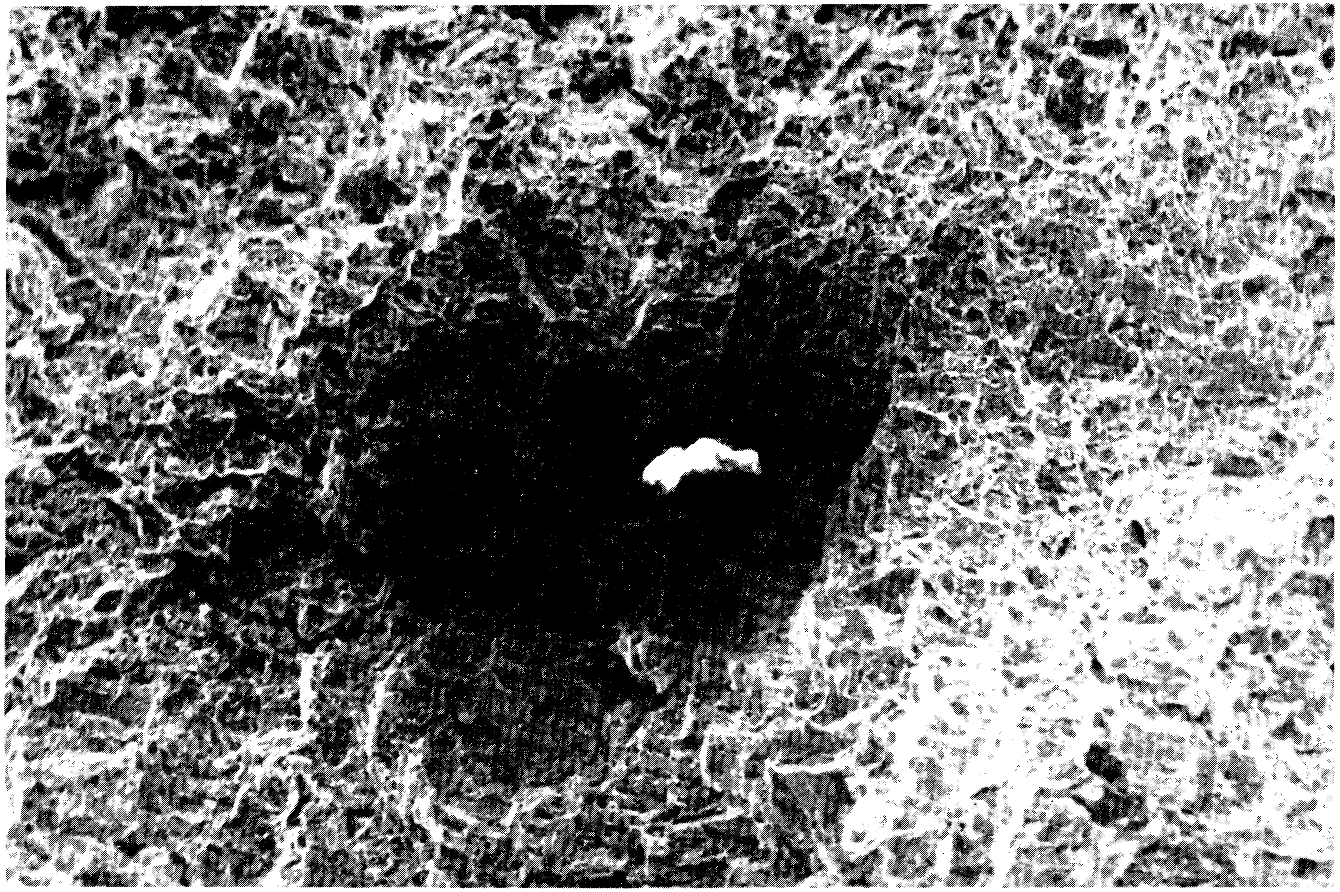


Figure 13. The bottom of a fissure in a tensile fracture surface from a Web-Webbert test specimen. The bright area "glows" in the scanning electron microscope since it is nonmetallic and takes on a surface charge. 100X. The metal showed 8% elongation and a gas pressure of 160 mm Hg.

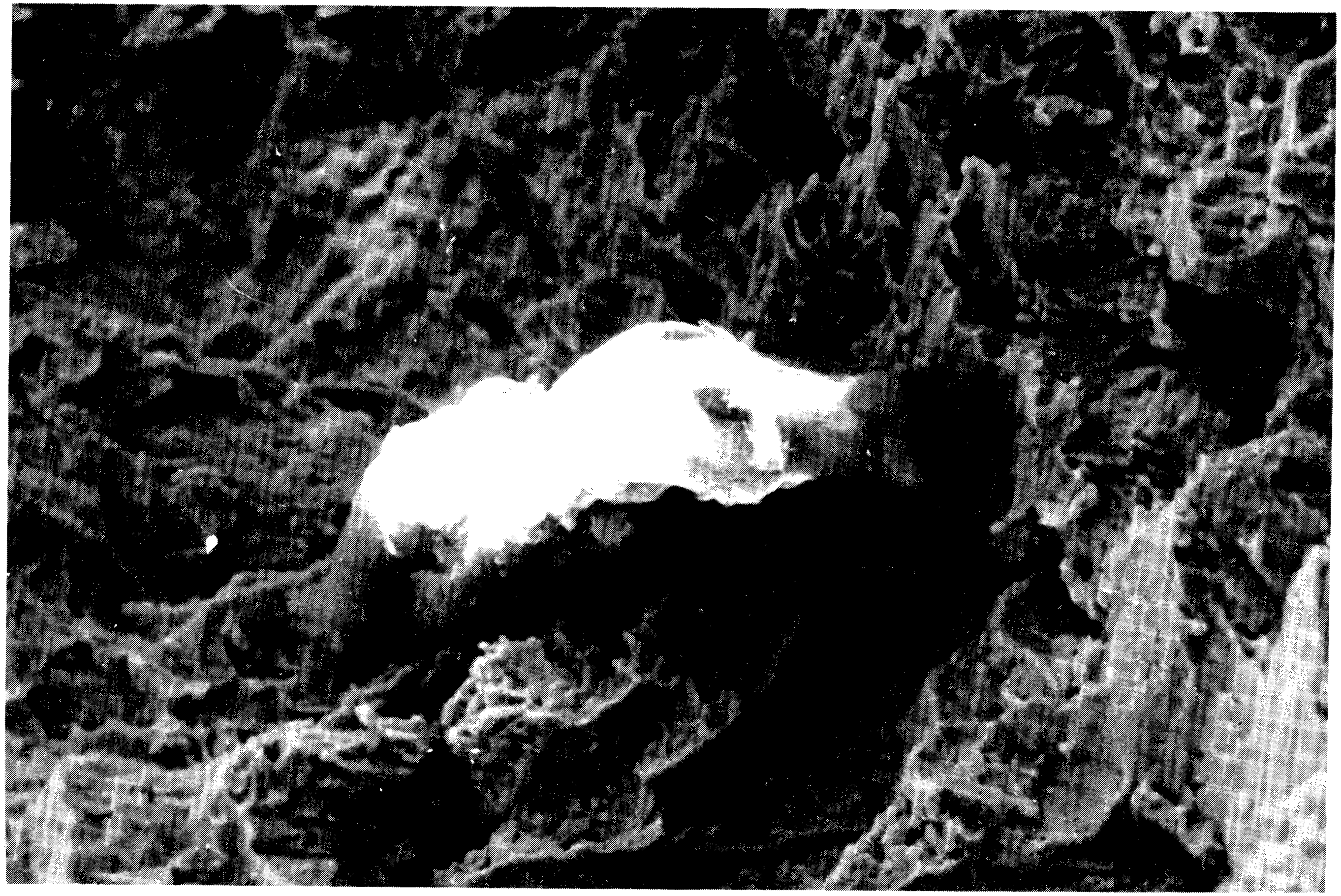


Figure 14. A closer examination of the nonmetallic particle in Fig. 13. The particle appears to be coherent with the matrix. 500X.