THE INFLUENCE OF GAS POROSITY UPON THE MECHANICAL PROPERTIES OF ALUMINUM BRONZE

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ABSTRACT

This report summarizes the results of the second year's research on the measurement of gas in aluminum bronze, its effects upon mechanical properties and methods of elimination.

The investigation of melting variables was continued and a simplified test for general production use developed. The test equipment requires only a steel test chamber, a simple vacuum pump, storage bottle and pressure gage. A sample is dipped from the melt, placed in the test chamber, allowed to solidify to 1/4 of the crucible radius and the reduced pressure applied. The gas pressure of the melt is determined by finding the reduced pressure which just develops a slight but definite rise in the melt surface without breaking of the bubble.

Using this test the effect of rate and time of purging with nitrogen were evaluated. The effect of varying the analysis from 953(9B) and 954(9C) in both induction and gas furnace melting was found to be negligible.

The effect of gassy versus degassed metal upon the mechanical properties in different section thicknesses was determined for alloys 954(9C) and 955(9D). In general the Web-Webbert and 1 in. sections do not show any difference but the effect of gas is severe in 3 in. and 6 in. sections.

Introduction, Review of Previous Work

The objectives of this research are:

(1) To determine the factors in melt practice which govern the gas content of aluminum bronze in the furnace.

(2) After obtaining different gas levels in (1), to evaluate the effects of mold material and mold design (section thickness, chilling) on the gas porosity in the casting.

Gas porosity has led to frustratingly large amounts of scrap castings in many alloys. In the case of aluminum bronze, it has not even been possible from the varied operating reports to assign the cause of porosity to gas dissolved in the metal in the furnace or to gas picked up by the metal from the mold. The precise roles of purging with nitrogen, of degasifiers, and of casting design have not been defined.

Accordingly in 1971, the first year's work on this project was started under the sponsorship of the International Copper Research Association.[1] During the past year the work has been supported by the Technical and Research Institute of AFS.

The findings of the first year should be reviewed briefly because of the close relation to the new work. The results were in two parts:

1. Measurement and control of gas in the melt. First an accurate reproducible test for evaluating the gas content in the melt was developed. The essence of the test is to allow a crucible of liquid metal to solidify a given amount and then apply a predetermined reduced pressure over the melt. The value

of reduced pressure which barely permits gas evolution is an index of the gas pressure of the melt. A convenient method of regulating the gas pressure of the melt was to produce an atmosphere saturated with water vapor over the melt for varying periods of time using dampened clay discs. After standardization of the test, the effects of natural furnace atmosphere (gas furnace vs induction), melting temperature, holding time, and purging with N_2 were investigated.

2. Mold variables. In this category it was shown that high moisture levels in greensand led to porosity. Plate castings of different thickness and with different chill configurations were investigated.

After review of the first year's work with the AFS Brass and Bronze Research Committee, the following objectives were set for 1972-73:

1. Control of gas in the melt.
    - A. Simplification of the reduced pressure test to permit general use in the foundry.
    - B. Evaluation of the effect of rate and time of nitrogen purging.
    - C. Evaluation of degasifiers.
    - D. Comparison of gas effects in alloy 953(9B) with 954(9C).
    - E. Vacuum fusion analysis.
2. Mold variables - Alloys 954(9C) and 955(9D).
    - A. Effect of section thickness.
    - B. Effect of chilling.

General Procedure

Since a variety of procedures were involved only the general outline will be described here and the specialized procedures will be reviewed with the results.

The melting equipment consisted of a 3000 cycle 50 KW lift coil induction furnace using clay graphite crucibles. The maximum melt weight was 160 lb. To evaluate gas atmospheres a small gas fired (25 lb) furnace was used for flexibility but it is planned to check the results with an available commercial size unit (200 lb).

Temperatures were measured in all cases with a Pt-Pt 10% Rh immersion thermocouple. Pouring temperatures, sand composition, and other details are given in the appropriate sections.

The charge consisted of analyzed ingot provided by R. Lavin & Sons or of ingot plus remelt. Since in all cases the gas pressure of the melt was adjusted and measured, the original charge had little effect. A typical analysis (9C) is Cu 86.05, Al 10.25, Fe 3.29. No cover slag was used.

Details of casting design are shown in Figure 1.

Results

1. Control of gas in the melt

A. Simplification of the reduced pressure test.

In last year's report the standard test involved dipping a sample of metal with a preheated porcelain crucible, placing the crucible in a graphite seat in the (open) reduced pressure chamber, inserting a delicate (28 ga.) Chromel-Alumel thermocouple with a jig to locate it at 1/4 radius and 1 in. beneath the surface. The time for start of solidification was noted as an arrest in the temperature-time chart of the thermocouple and 15 sec later the pressure was reduced to a preselected value. The gas pressure of the melt was obtained when the imposed pressure gave a gentle rise in the melt surface without bubbles breaking through.

After a number of tests, a simpler procedure was developed. By watching solidification proceed inward from the wall of the crucible, the time at which a solid front has developed to the 1/4 radius position on the surface can be estimated quite accurately. At this point the valve to the vacuum tank is opened to provide the desired value of reduced pressure in the chamber. The observation of the surface is done as in the old method.

A further simplification is possible after some experience with the effects of gas pressure in the melt on porosity in a given casting. For example, assume that from previous experience and experimentation it is found that a melt gas pressure of over 80 mm will cause porosity in the particular castings to be poured. It is not necessary then to measure the exact gas pressure in a given melt but merely to make sure that it is below 80 mm. The vacuum tank is set to provide a reduced pressure of 70 mm for safety and if no bubble is noted the metal is cleared for pouring.

In summary then the only equipment required is a reduced pressure chamber with a glass window, a pressure gage, a vacuum pump and a vacuum tank for which one or two empty oxygen or other gas tanks can be used as ballast volume. The dimensions and connections are in Reference 1.

B. Evaluation of the effect of rate of nitrogen and time of nitrogen purging.

The effect of rate of purging was investigated by immersing a carbon tube 3/4" ID x 2" OD with a porous graphite plug at the bottom. The heats in the lift coil induction furnace were 60 lb. The gas flow rate was metered with a Rotometer with a range of 0-10 l/min.

First the melts were gassed with wet clay discs to give an initial gas pressure of 220 mm Hg. Three different flow rates were selected. First the maximum rate which could be tolerated without severe spatter was determined as 2 liters/min. Then the two other rates were selected as 1 l/min and 0.5 l/min. At intervals during purging, crucible samples were dipped and pressure tested. The results are shown in Figure 2. Downward arrows indicate that a bubble did not form in the sample, while upward arrows show the bubble broke at least once and the gas pressure should be higher. Therefore, the curves in Figure 2 lie between the experimental points unless an exact gas pressure valve showing a single non-breaking bubble happened to be selected. (See ref. 1).

In general the results indicate that at all nitrogen flow rates the purging was quite efficient. Also within the range tested a simple linear decrease in gas content with time is obtained. Of course as might be anticipated higher flow rates lead to lower gas pressures.

C. Evaluation of degasifiers.

Occasionally a degasifier, usually an alloy with active elements such as titanium and zirconium, is suggested for gas control. A simple test was made with the addition of 0.5 wt percent of a proprietary alloy #77 and the results are given in Figure 3. Apparently the addition reduces the gas pressure quickly and then the gas continues to decrease after holding in the induction furnace.

D. Comparison of gas effects in alloy 953(9B) vs 954(9C).

To complete the investigation of variables affecting the gas content of the melt, compositional changes in the four alloys 953, 954, 955 and 956 are being evaluated. It was decided to begin this section of the work with 9B because of the variation in iron content compared with 9C (1% versus 4% Fe).

Parallel heats in both induction and gas furnaces were made with both alloys as shown in Figure 4. The rates of gas pickup from the successive addition of clay discs are approximately the same although alloy 954 has generally a slightly higher gas content than alloy 953. It should also be noted that alloy 954 in the gas furnace does not have a plateau at 20 clay discs as originally presented in a previous paper.[1]

A heat of 953(9B) was tested to determine the effect of holding time on gas content using the gas furnace, Figure 5. The rate of decrease is similar to earlier data for 954(9C) but the test was discontinued before an equilibrium value or plateau was reached. The initial loss rate was approximately 3.5 mm Hg/min for 954 (ref. 1) and 5.0 mm Hg/min for 955. It is interesting to compare these values for the gas furnace with the induction furnace (Fig. 2) at a value of 10.0 mm Hg/min.

E. Vacuum fusion analysis.

To this point only the evaluation of the total gas content of the melt has been discussed since this appeared to be the simplest way to provide a practical measurement for production conditions. However it is of basic importance to determine the analysis of the gases causing porosity. Efforts were made to analyze the gases evolved in the reduced pressure chamber using a mass spectrometer but no worthwhile results have been obtained. In addition, samples were obtained from the melt in Vycor suction tubes, refrigerated immediately and analyzed by vacuum fusion with the results shown in the following table:

9C gassed with 30 discs in induction furnace

Treatment	Hydrogen (ppm)	Oxygen (ppm)
as gassed	1.4	3.5
held 5 min	.95	2.5
held 10 min	1.0	5.5
held 15 min	.80	4.5
held 20 min	.75	2.5

The only significant trend seems to be a decrease in hydrogen with holding time. Further work is needed on the combined role of hydrogen and oxygen on their ability to form water vapor and hence gas porosity.

2. Mold variables - alloys 954 and 955

A. Effect of section thickness.

Previous work[1] had shown that gas porosity increased in the range 1/2 in. to 2 in. plates. In view of the interest in this phenomenon and in gas porosity in still heavier sections, a series of castings was poured in the "gassed" and "degassed" conditions. These included Web-Webbert, 1 in. Y unchilled, 1 in. Y chilled at bottom, 3 in. Y and 6 in. Y blocks. The molds were made of #80 silica sand with No-Bake binder. The gas pressures in the melt were 266 mm in the as gassed condition and below 23 mm in the degassed condition. Both alloys 954(9C) and 955(9D) were poured at 2230-2260°F. The following heat treatments were used for the samples marked "heat treated": 1650°F-1 hr-water quench, temper 1 hr 1100°F, water quench. The results are shown in Figures 6, 7, 10 and 11.

In 954(9C) (Fig. 6,7) the properties are essentially the same for gassed and degassed metal in the Web-Webbert and 1 in. sections. However, in the 3 in. and 6 in. sections the tensile and yield strength are higher in the degassed material. There is a striking difference in elongation with the degassed bar exhibiting much better values. Tensile bar fractures are shown in Figure 8.

This effect is confirmed by the overall view and the radiographs, Figs. 9, 10. The 1 in. block is relatively gas free in the gassy melt, the 3 in. block shows gas especially in the upper portions while the 6 in. block is uniformly gassy. Shrinkage in the riser sections (Fig. 8) also gives visual evidence of the gas content.

In alloy 955(9D) the decline in properties is not encountered until the 6 in. section is reached, Figs. 11, 12. There it would appear alloy 9D might be more tolerant of gas in larger sections.

B. Effects of chilling.

In previous work involving plates which were cast horizontally, it was found that chilling on the sides did not reduce porosity in the casting. The only effect was to obtain long streaky gas holes in place of the round type encountered in unchilled castings. However because of the importance of chills it was decided to carry on the experiments with 1 in. Y blocks chilled on the bottom. In this case the chills promoted directional solidification upward and the effect was sufficient to drive the gas out of the test bar section in a gassy melt.

Figures 13 and 14 show closeups of the cavity in the riser in chilled 1 in. blocks of alloy 954 poured from gassy and ungassed metal. In the ungassed metal the walls of the cavity are rough with dendrites and the cavity is due simply to shrinkage. In the gassed metal the walls of the cavity are smooth and the cavity is due to a combined gas and shrinkage effect.

Conclusions and Recommendations for Future Work

1. Gas content of the melt. A simplified pressure test has been developed which can be readily used in production. The effects of rate and time of nitrogen purging have been evaluated. Preliminary tests of degasifiers are encouraging and should be continued. There appears to be little difference in the susceptibility to gas of 953(9B) and 954(9C) and simple experiments should be conducted to determine if 952(9A) and 955(9D) behave similarly. Initial vacuum fusion tests are interesting and should be continued to determine the basic nature of the melt gas.

2. Mold variables. The Web-Webbert and 1 in. Y blocks do not distinguish between gassy and degassed metal because the thermal gradients provide for gas escape from the test bar section. In 954(9C) the properties of the 3 in. and 6 in. sections are severely reduced by gas and in 955(9D) the 6 in. section is severely affected. The work should be continued over a range of gas levels and for other alloys and with different mold materials.

Acknowledgments

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We are also grateful for the material and analysis donated by R. Lavin and Sons.

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References

1. Y. Matsubara, P.K. Trojan, S. Suga, and R.A. Flinn, "Gas Porosity in Copper Alloys - Part I. Aluminum Bronze," Trans. Amer. Fndrymen's Soc., Vol. 80, 1972.

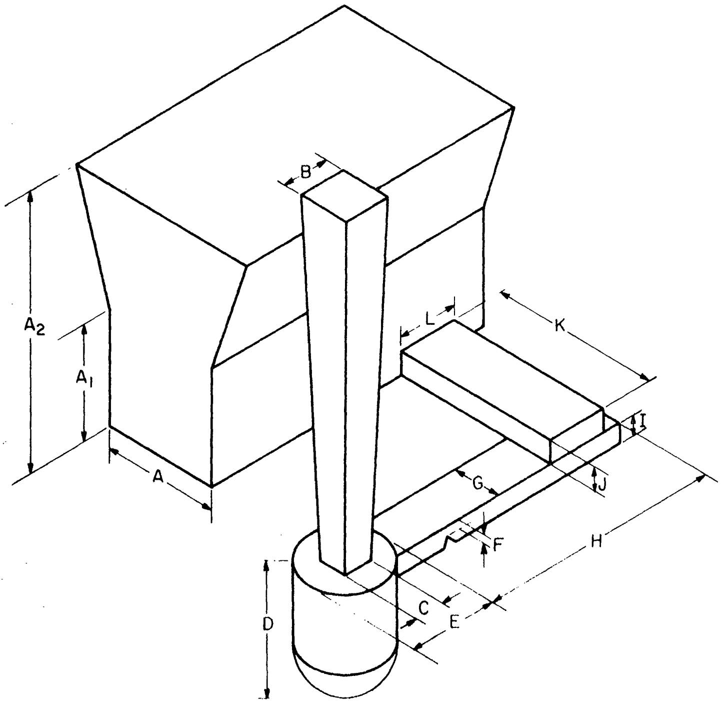

TABLE OF GATING SYSTEM DIVISIONS
(all Numbers Given in Inches)

A	A_1	A_2	B	C	D	E	F	G	H	I	J	K	L
Y-block Width	Y-block Height	Y-block Height	Sprue Top	Sprue Bott.	Well Depth	Well Diam.	Choke	Runner Width	Runner Length	Runner Height	Gate Height	Gate Length	Gate Width
	Test Section	Over-all											
1 in.	1.3	4.2	0.75	0.5	1.6	1.6	0.15	0.65	4.1	0.3	0.5	2.4	0.9
3 in.	2.5	5.5	0.75	0.5	1.6	1.6	0.2	1.0	5.8	0.4	0.5	4.3	1.7
6 in.	2.5	5.5	1.0	0.7	1.9	1.8	0.3	1.5	6.5	0.65	0.75	3.5	2.4

Figure 1. Details of Y-block castings used in the correlation of section size with mechanical properties and gas porosity.

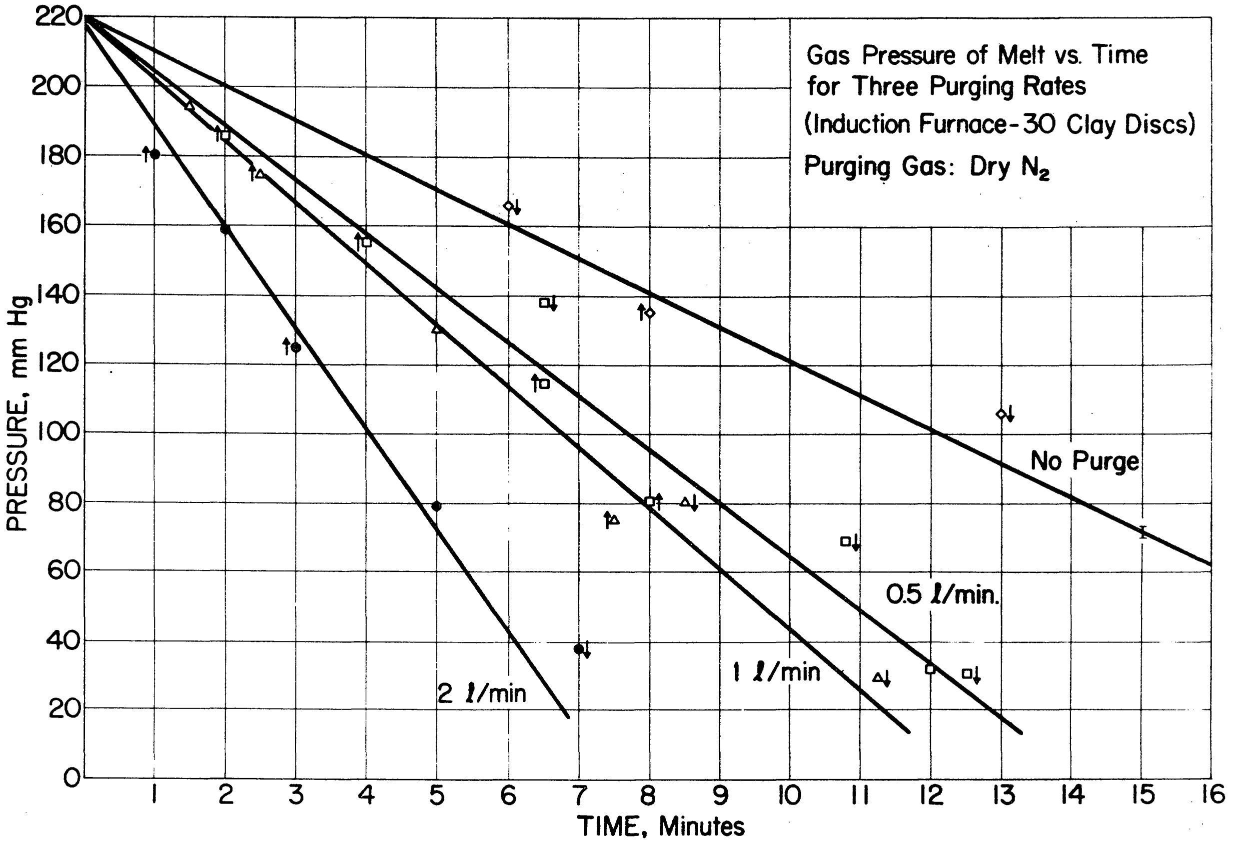

Figure 2. The effect of nitrogen flow rate during purging on the residual gas pressure of the melt.

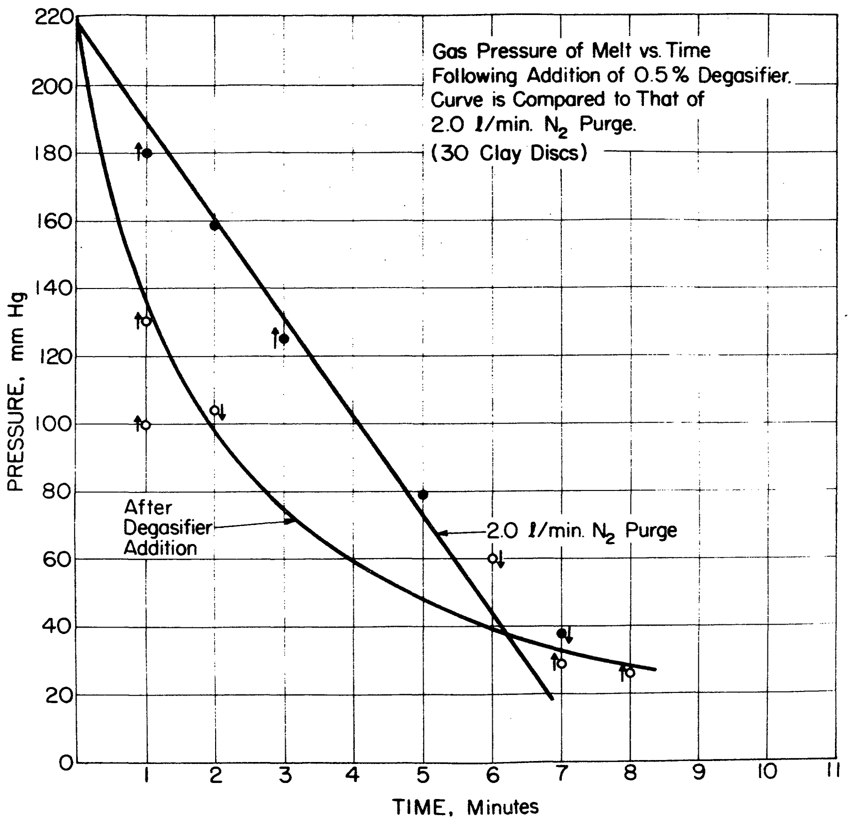

Figure 3. A comparison of a high nitrogen purging rate with a commercial degasifier and their ability to lower the melt gas pressure.

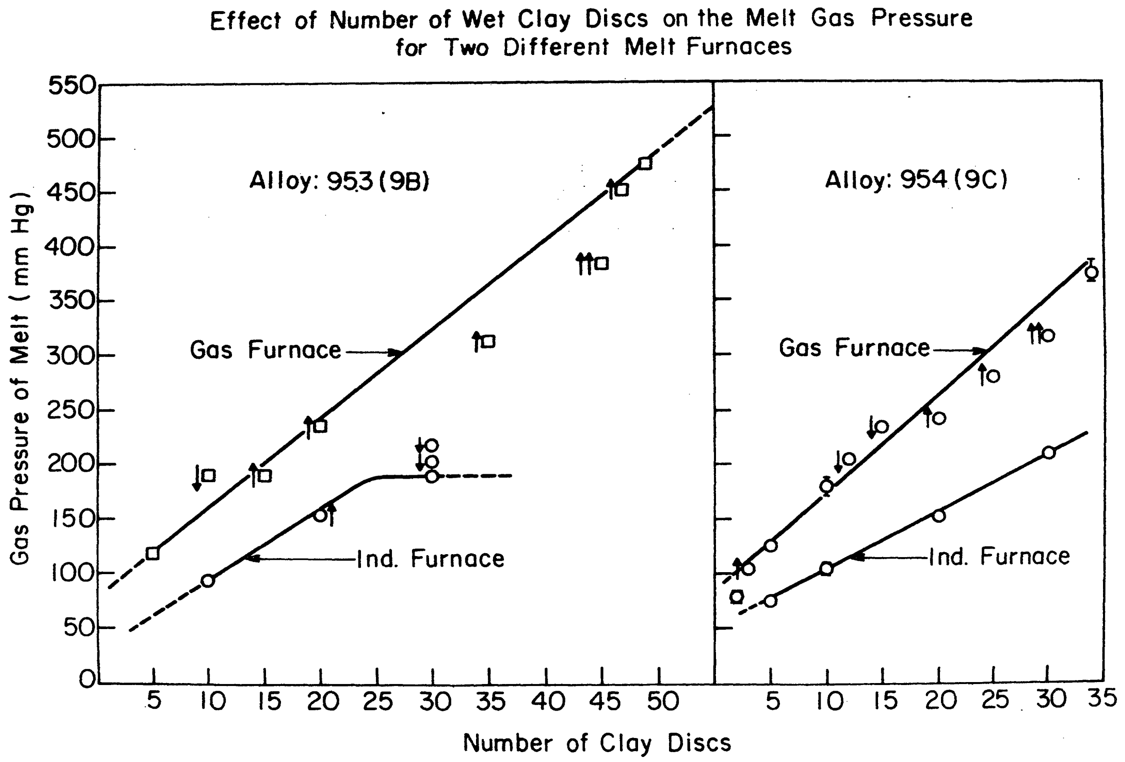

Figure 4. The effect of clay disc additions on the melt gas pressure for both alloys 9B and 9C when melted in the induction furnace and gas furnace.

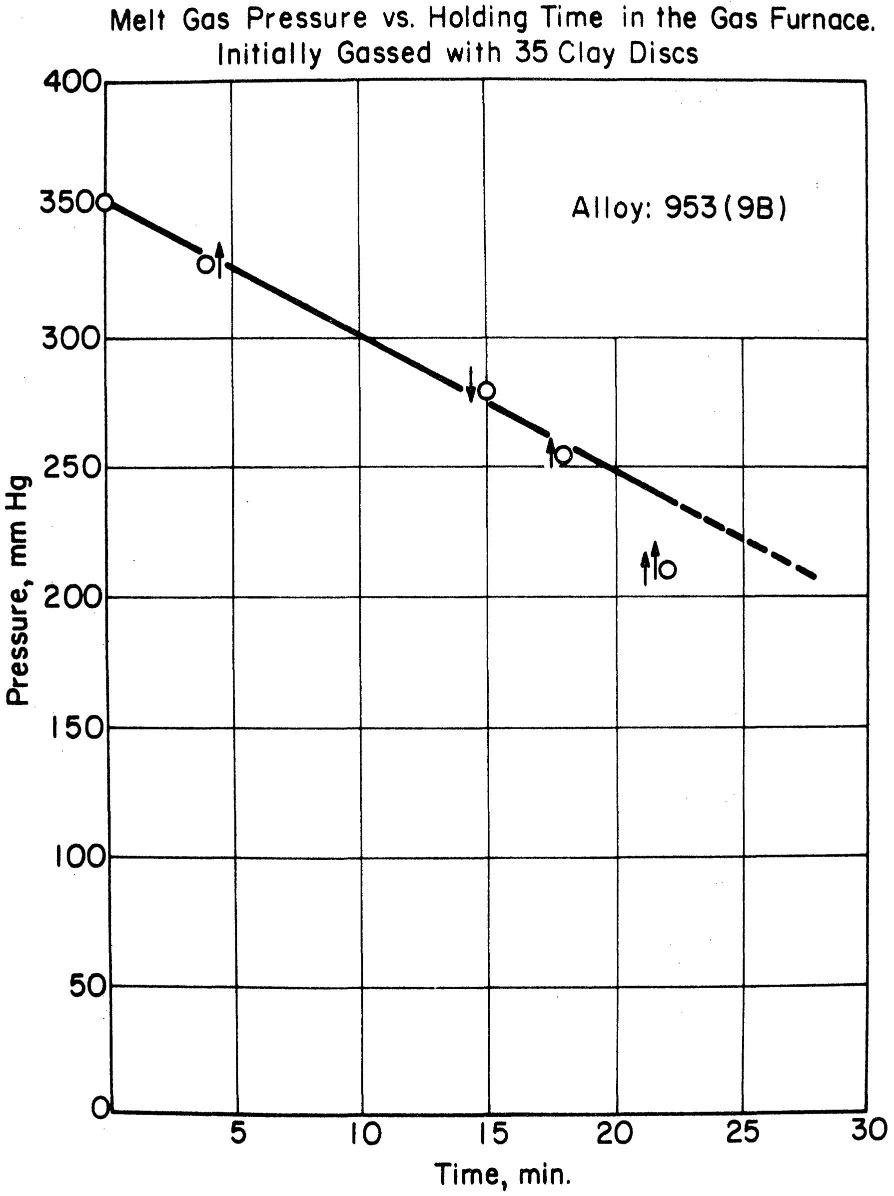

Figure 5. The rate of gas decrease in originally highly gassed 9B alloy when held for extended periods in a gas furnace.

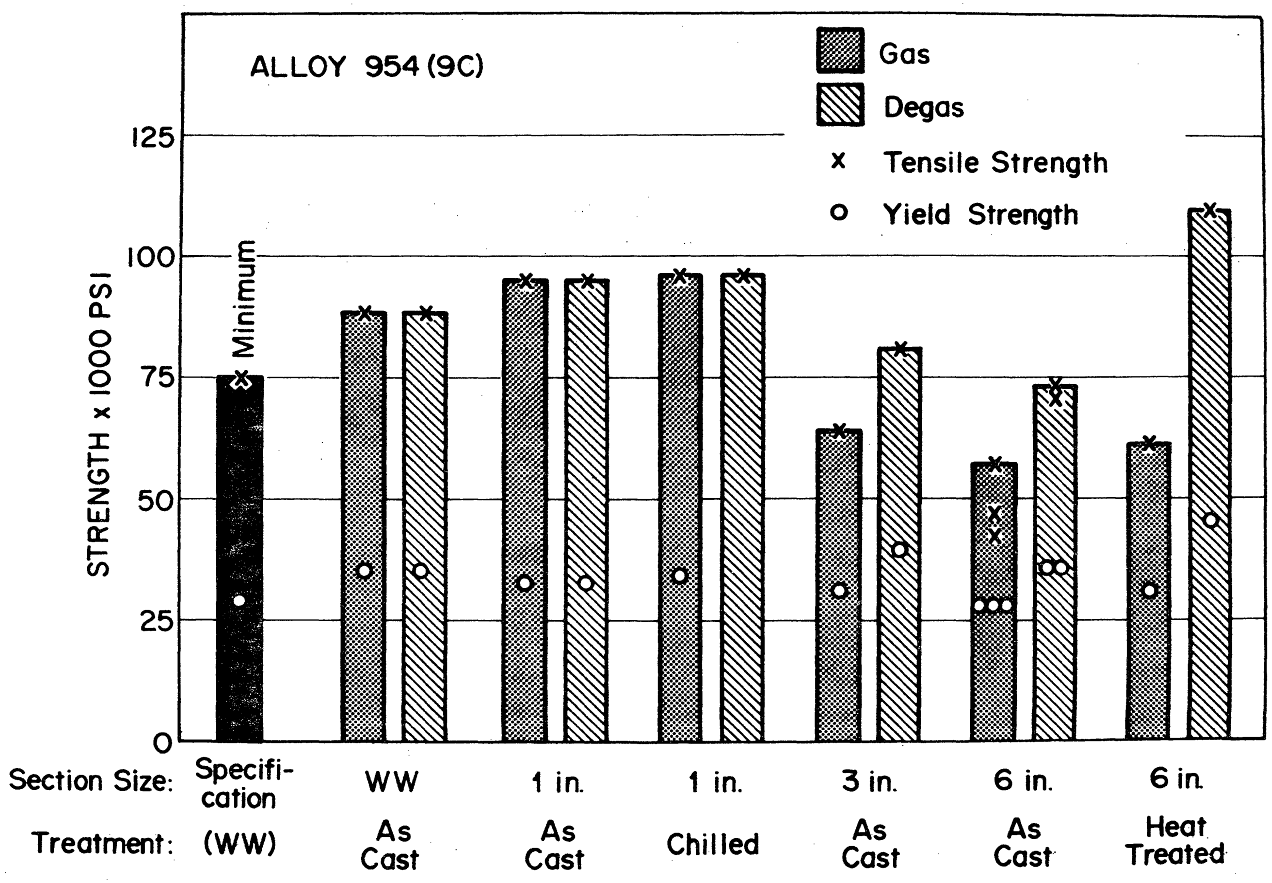

Figure 6. The effect of section size on the tensile strength and yield strength of 9C alloy when in the gassed and degassed conditions.

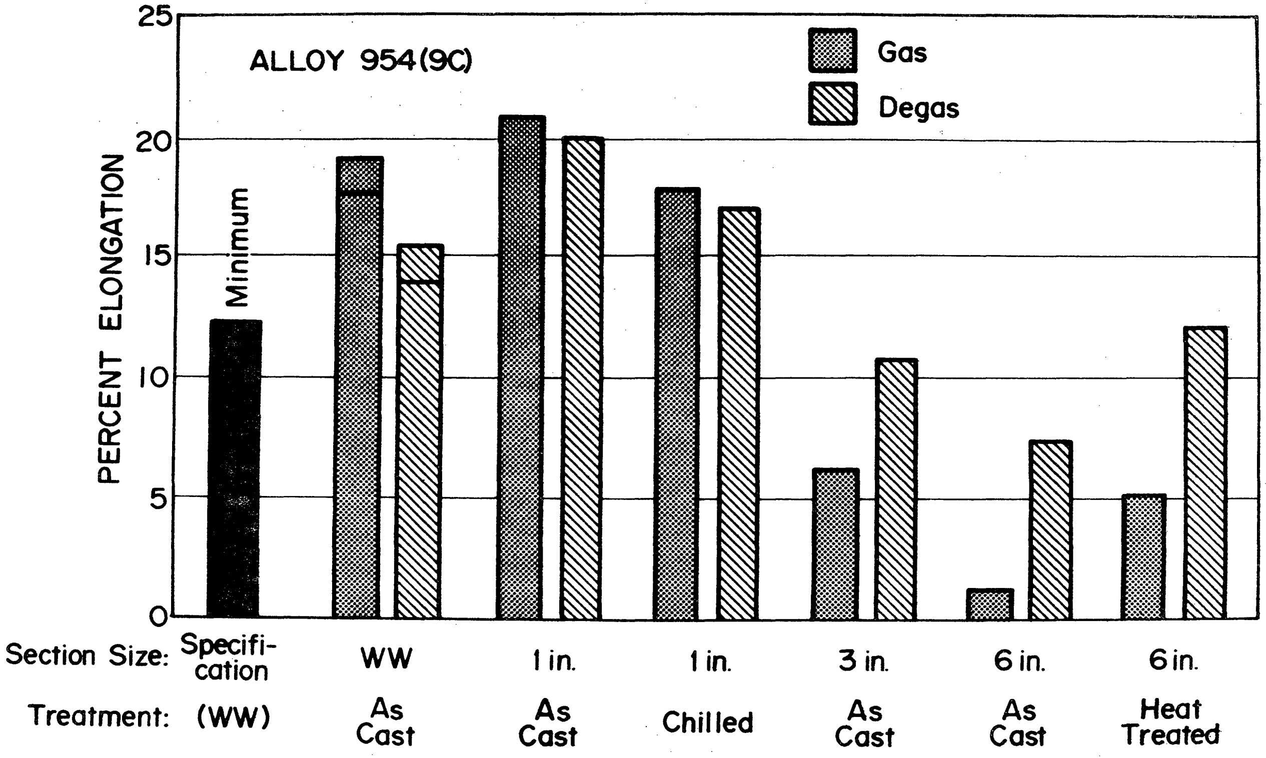

Figure 7. Elongation of 9C alloy as related to section size and gas content. The appearance of double bars indicates duplicate tests.

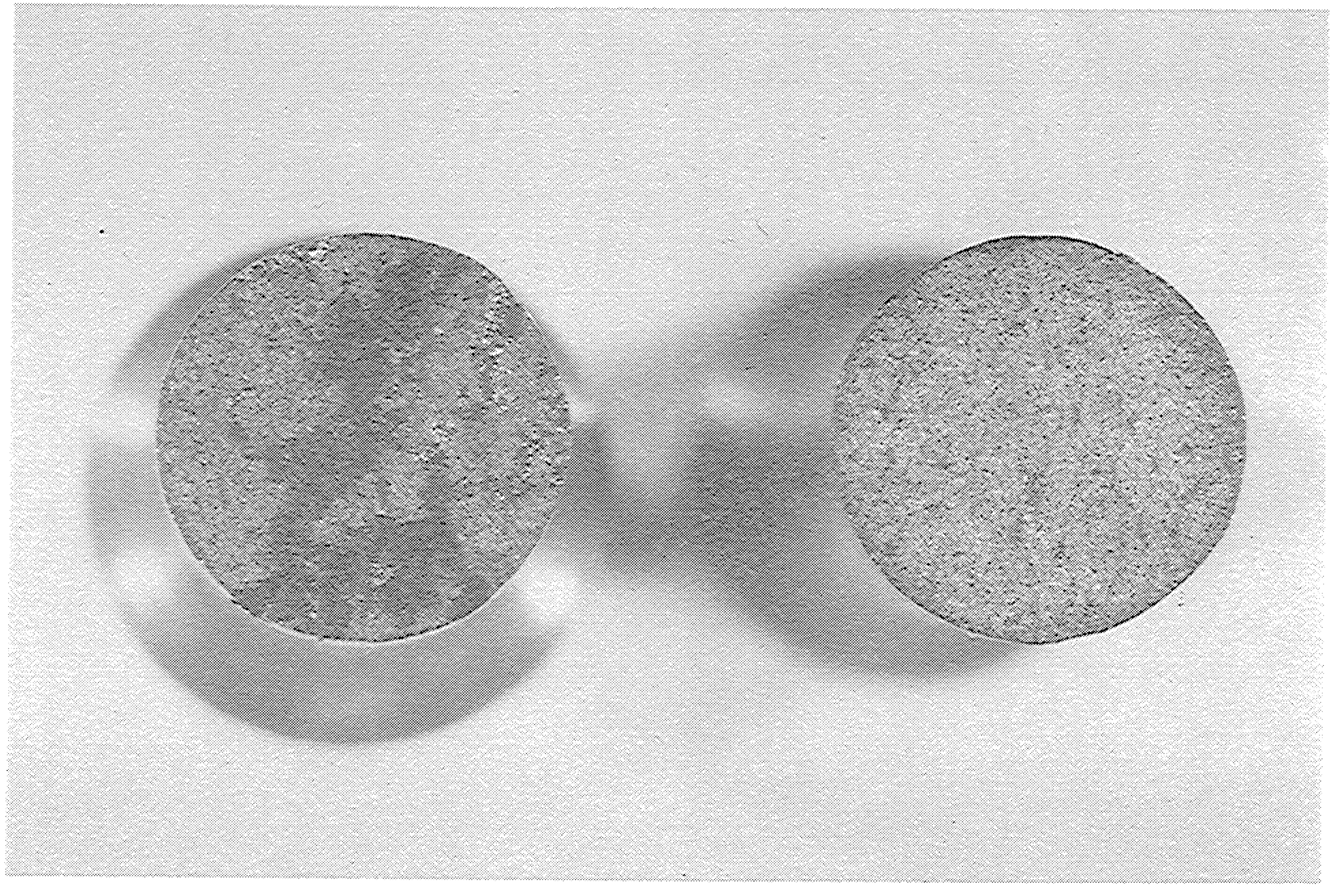

Figure 8. Tensile specimen fractures taken from 6 inch Y-blocks of alloy 9C. The specimen on the left was from gassy metal while the one on the right had been degassed.

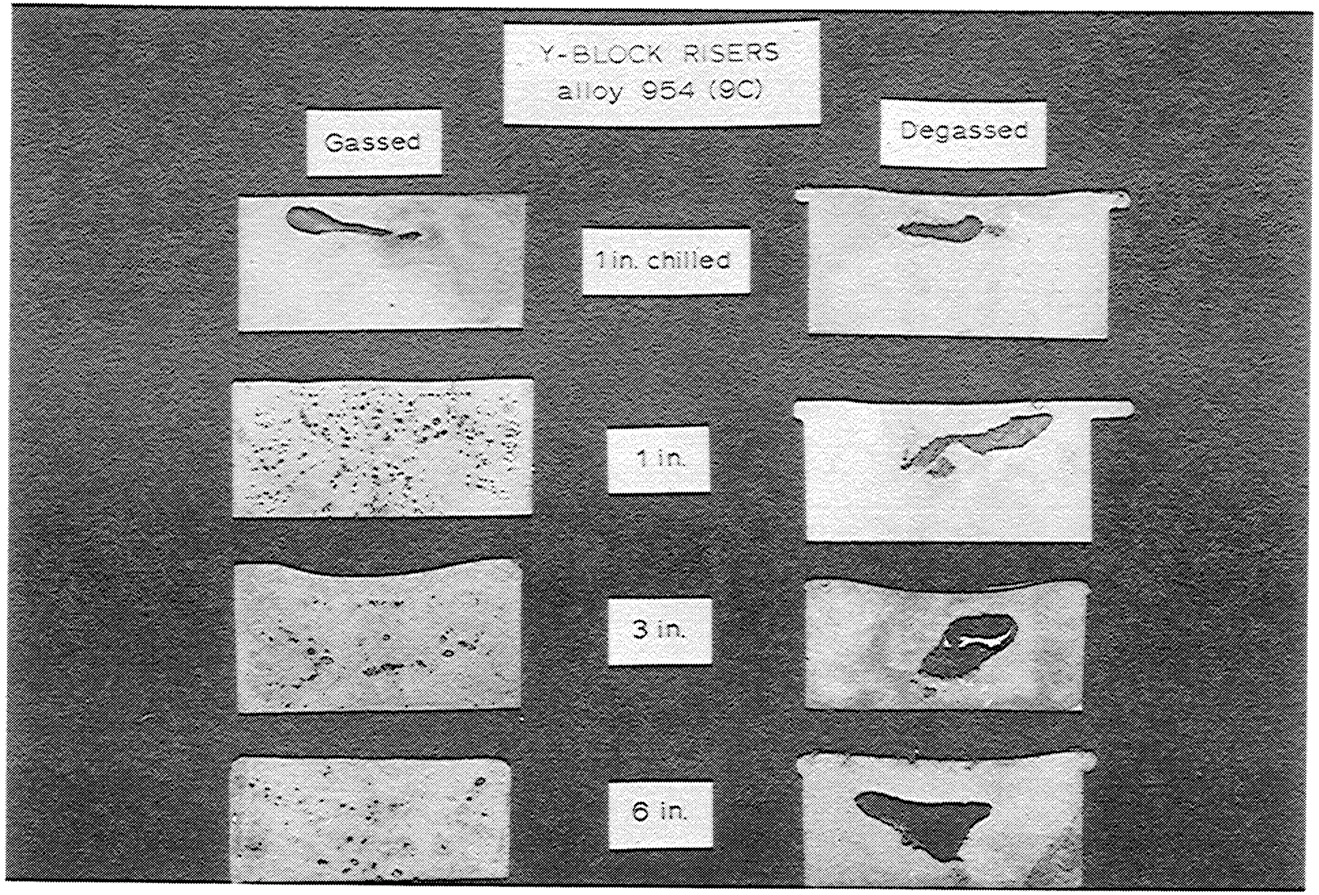

Figure 9. Overall view of the risers from the Y-blocks poured in alloy 9C in the gassed and degassed conditions. The gross shrinkage of the riser (or lack of it) is an excellent index of the gas presence.

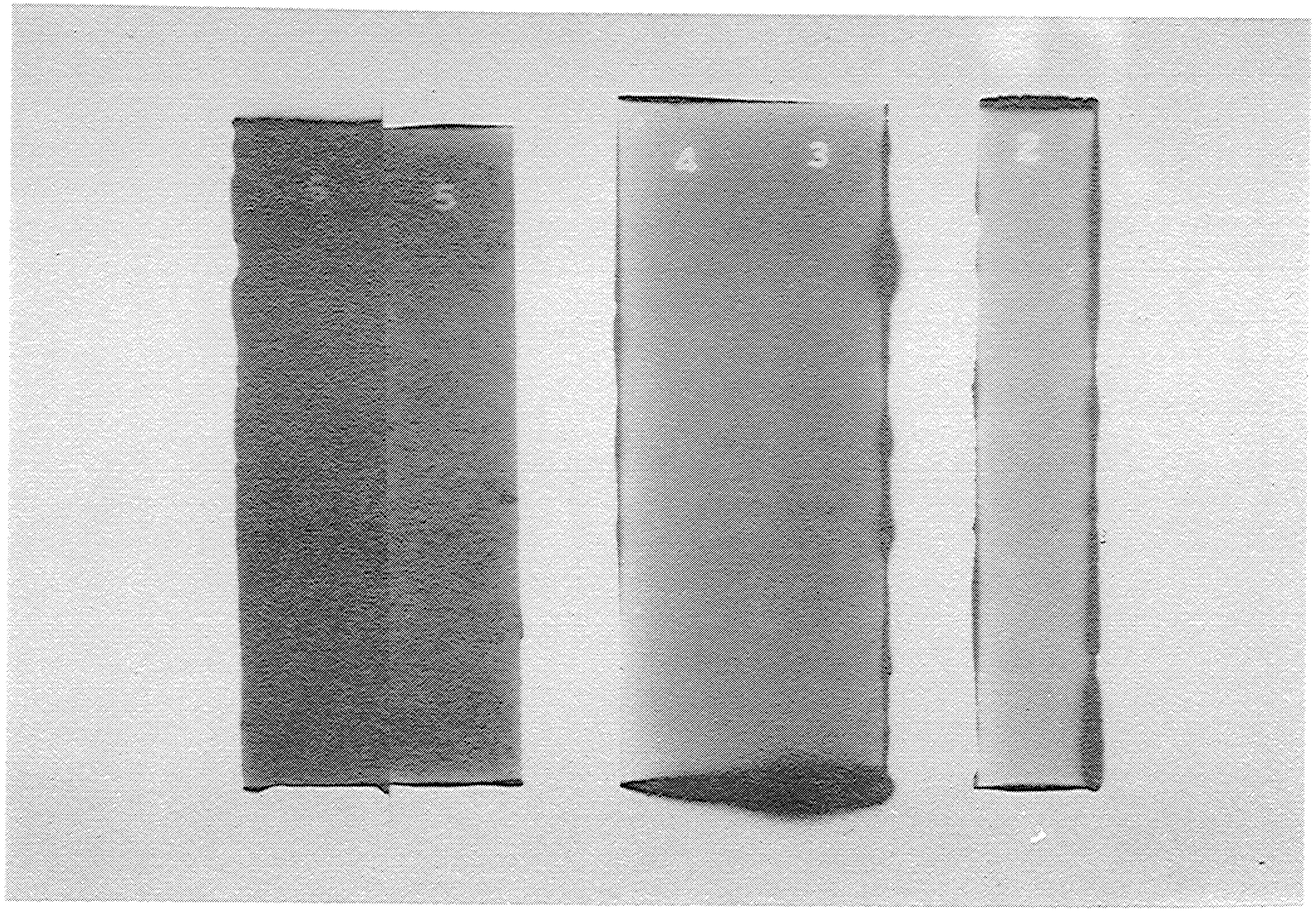

Figure 10. Radiographs of the test sections of a gassy 9C melt. No. 2-1" section (no gas visible; No. 3,4-3" section (some gas evident near the top-position 3); No. 6 & 5-6" section (gas more or less uniformly distributed.)

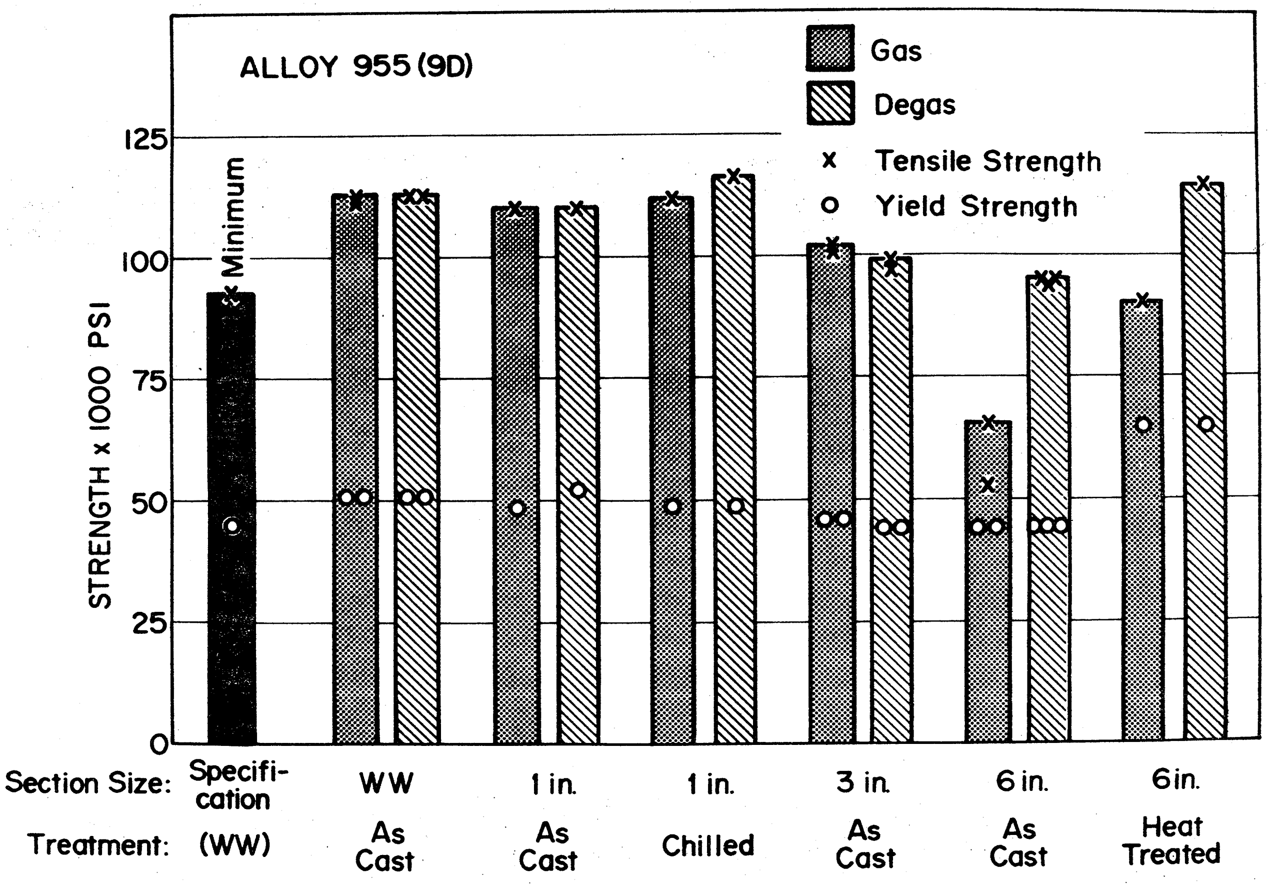

Figure 11. Tensile strength and yield strength of alloy 9D in the gassed and degassed condition for the series of test sections.

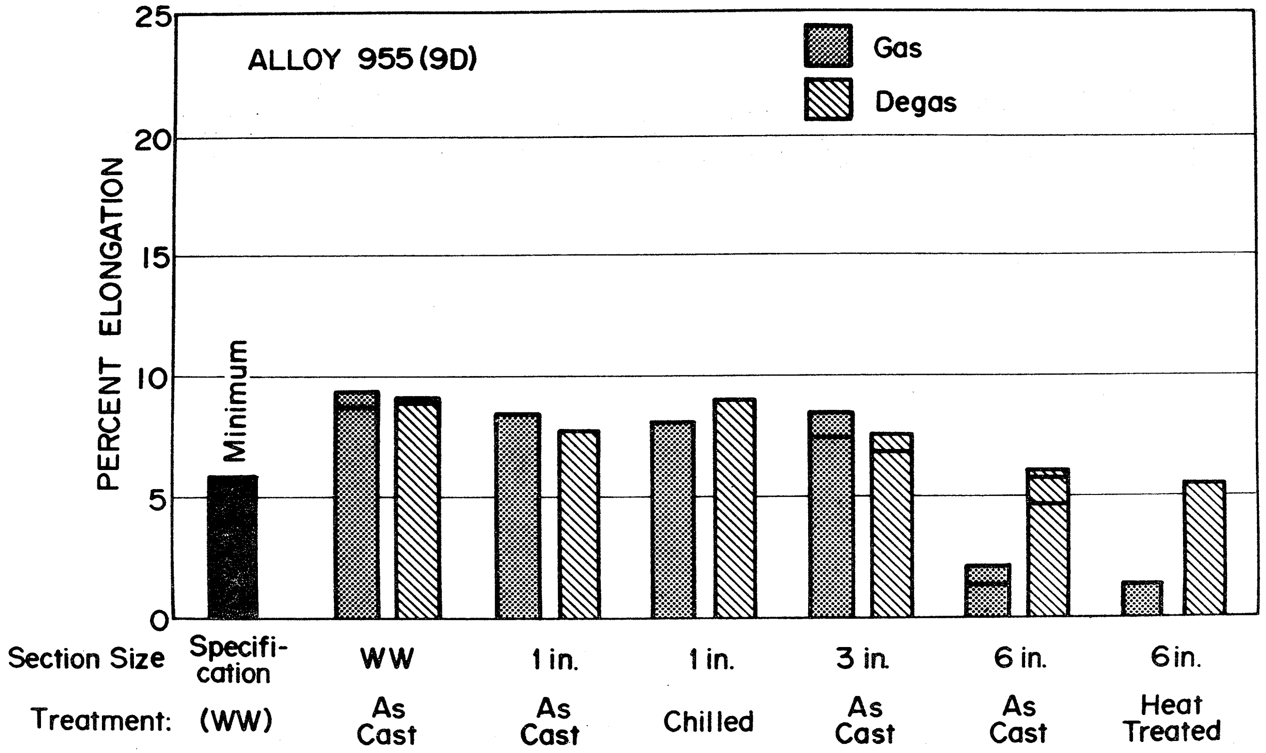

Figure 12. Elongation of alloy 9D as a function of section size and whether gassed or degassed. The appearance of double bars indicates duplicate tests.

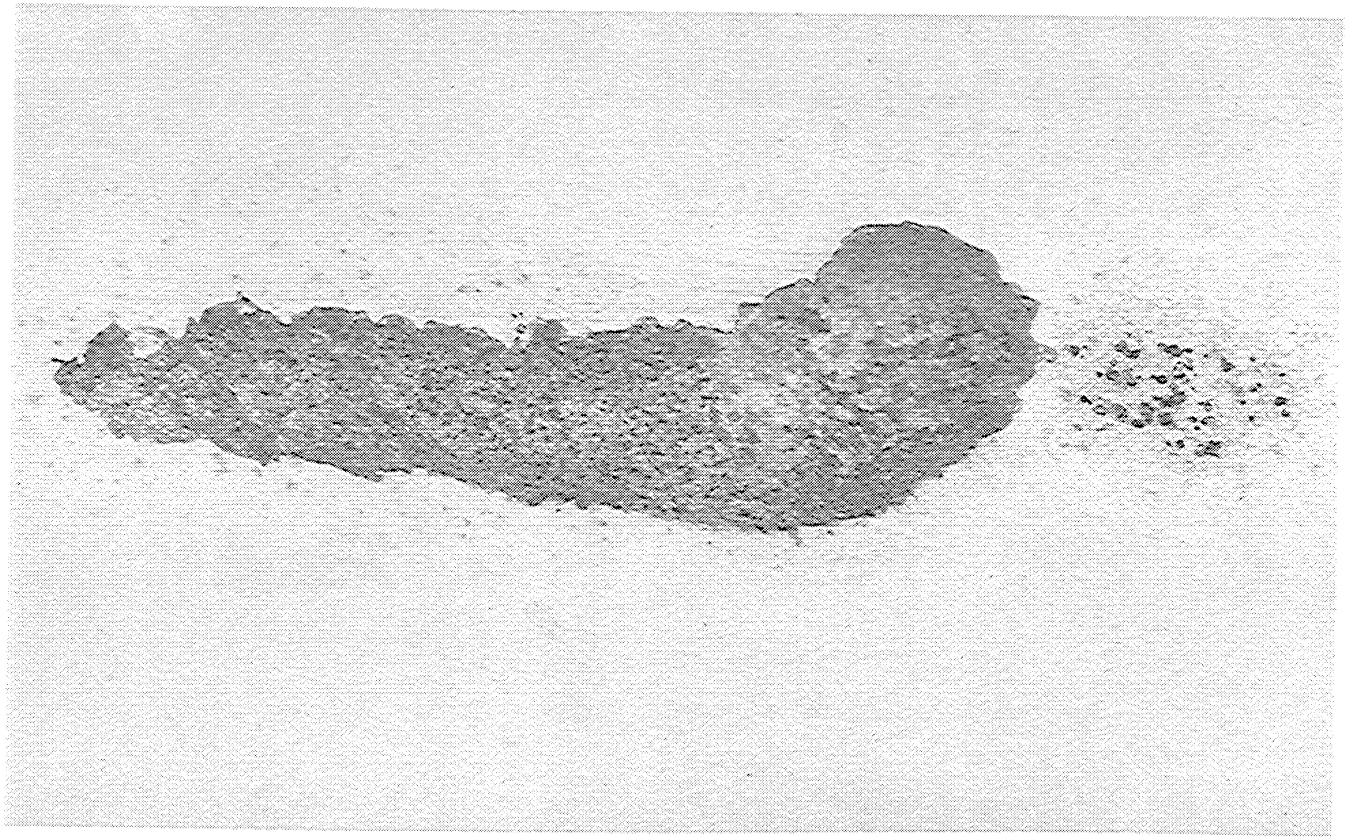

Figure 13. Closeup of the shrinkage cavity in the 1" chilled Y-block poured from degassed 9C metal. Note the rough appearance characteristic of dendrites.

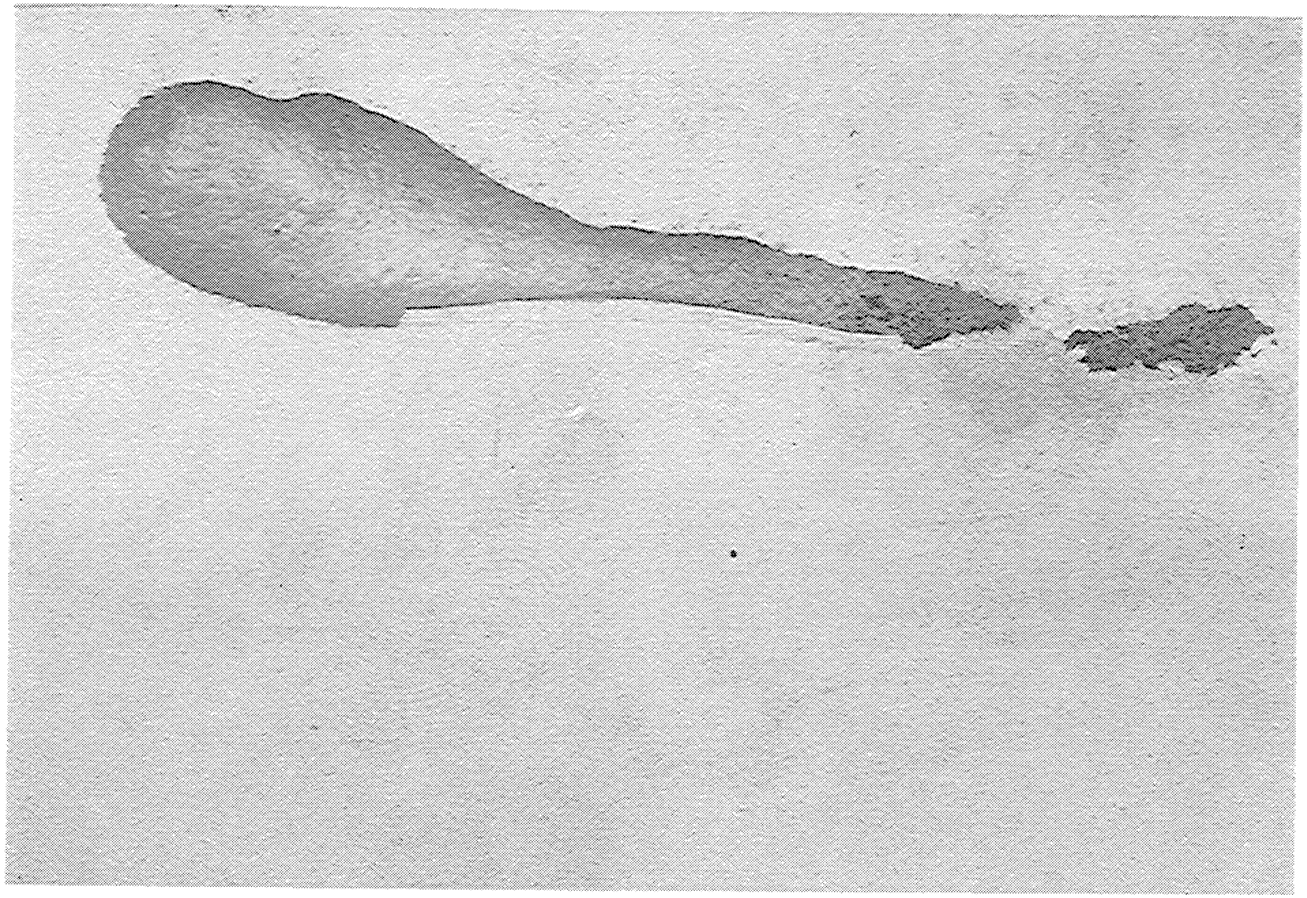

Figure 14. Closeup of shrinkage from gassy 9C alloy poured in a 1" chilled Y-block. In this case the cavity is smooth.