N R L REPORT NO. M-3254

THE VALUE OF PRESSURE TESTS AND RADIOGRAPHS OF GUN METAL CASTINGS

William H. Baer

Approved by:

Mr. B. M. Loring, Head, Nonferrous Group
Mr. R. W. Tindula, Head, Melting and Casting Section
Dr. O. T. Marzke, Superintendent, Metallurgy Division

Problem No. 35M01-08 March 8, 1947

NAVAL RESEARCH LABORATORY
CAPTAIN H. A. SCHADE, USN, DIRECTOR
WASHINGTON, D.C.

DISTRIBUTION

BuShips	(5)
BuAer	(2)
BuOrd	(2)
ONR Attn: Code N-482	(2)
Cdr., Boston Naval Shipyard	(2)
Cdr., Brooklyn Naval Shipyard	(2)
Cdr., Charleston Naval Shipyard	(2)
Cdr., FPO, San Francisco	(2)
Cdr., Mare Island Naval Shipyard	(2)
Cdr., Norfolk Naval Shipyard	(2)
Cdr., Philadelphia Naval Shipyard	(2)
Cdr., Portsmouth Naval Shipyard	(2)
Cdr., Puget Sound Naval Shipyard	(2)
Cdr., San Francisco Naval Shipyard	(2)
Cdr., Terminal Island Naval Shipyard	(2)
Dir., USNEL, San Diego, California	(2)
CO, NTS, Newport, Rhode Island	(1)
Dir., USNEES, Annapolis, Maryland	(1)
Dir., USNML, Munhall, Pennsylvania	(1)
OinC., USNOL, NGF, Washington, D. C.	(1)
Supt., NGF, Washington, D. C.	(1)

CONTENTS

ABSTRACT

Cast gun metal plates 1 in. x 8 in. x 6 in. of composition 88 Cu - 8 Sn - 4 Zn, containing defective areas, were investigated by radiography and tested under hydrostatic pressure. After machining metal from both sides of the castings, radiographs were taken and the castings pressure tested at the new thicknesses. The plates were divided into four major classifications by the appearance of the radiographs of the one-inch section. Radiographs of castings that were pressure-tight and castings which leaked are shown. It was concluded that castings intended for critical use should be radiographed as well as pressure tested.

PROBLEM STATUS

This report concludes the work on this problem, and unless otherwise advised by the Bureau the problem will be closed one month from the mailing date of this report.

AUTHORIZATION

This problem was authorized in response to request of BuShips letter OP/Castings (334-692) to NRL dated 20 September, 1944 and was assigned NRL Problem Number 35M01-08.

THE VALUE OF PRESSURE TESTS AND RADIOGRAPHS OF GUN METAL CASTINGS

INTRODUCTION

The purpose of the investigation herein reported was to evaluate radiography as a means of inspection of gun metal castings in comparison with pressure testing.

It is customary to use the pressure test as the principal means of the evaluation of the quality of bronze pressure castings. The sensitivity of this test varies considerably with different conditions of testing. The pressure used, the medium for transmitting the pressure, and the time of application are important factors. More often than not, a change in one or more of these factors makes the pressure test a highly specialized test, even though it is almost universally accepted as one of the most practical means of measuring the degree of success attained in the manufacture of pressure castings.

The pressure test permits but limited interpretation of the cause or nature of a defect beyond the elemental fact that leakage takes place in a specified portion of the casting. In an attempt to remedy this failure of the pressure test a number of foundries have made initial investigations into radiography of bronze castings. Acceptance of the radiographic method of inspection has been retarded by the limited number of observations on which to base judgments. A few instances in which leakage have occurred in apparently radiographically sound bronze castings have raised considerable question of the reliability of this method. On the other hand, much can be pointed out regarding the pressure test that would make an occasional failure an expected occurrence under certain circumstances.

The limitations of both the radiographic and pressure testing methods of inspection stem from the nature of bronze castings. If a bronze casting has a superficially sound skin, the pressure test is a valid indication of expected service only insofar as the skin remains intact and undamaged. If fine capillaries of the metal are plugged with dirt during the pressure test and later become freed of the material, the pressure test as performed is valueless. Some of the imperfections which may not be revealed by the pressure test may also defy detection by radiographic examination. It is well known that fine cracks occurring transverse to the direction of the X-ray beam are unrecorded because they entail so little actual change in thickness. Interdendritic shrinkage may often be of this degree of fineness. From another point of view, the sound skin formation may be of such depth that serious defects revealed by radiography do not contribute to leakage in the pressure tests.

Considerable experience in radiography of bronze castings was obtained in the previous portion of this investigation, which was reported as "The Identification of Defects in Gun Metal by Means of Radiography," NRL Report No. M-2646, dated 1 September 1946. It was shown that characteristic differences existed between radiographs of defects such as shrinkage, gas porosity, and tears. The report was also concerned with the metallurgical factors

and foundry practice responsible for certain types of defects. No attempt was made to pressure-test the castings or assess the effectiveness of radiography as an inspection tool.

SEQUENCE OF EXPERIMENTS

Cast bronze plates of a composition of Cu 88 percent, Sn 8 percent, Zn 4 percent, initially one inch thick and 8 inches by 6 inches were examined by radiography and subjected to pressure tests. Those plates which leaked were not further investigated. Those which failed to leak were then reduced one-quarter inch in thickness by machining equal amounts of metal from the two sides of the plates and the examination and testing repeated. This procedure was repeated by quarter-inch reductions until the plates were one-quarter inch thick and at whatever thickness leakage developed, further examination of those plates was abandoned.

The plates were initially classified into four categories by the appearance of the radiographs of the one-inch section and numbered according to increasing severity of the radiographically detected nonuniformities. The four categories were: Light shrinkage, Table 1, medium shrinkage, Table 2, concentrated shrinkage, Table 3, and shrinkage combined with gas porosity, Table 4. The tables represent over two hundred pressure tests and radiographic examinations.

TABLE 1

RADIOGRAPH AND PRESSURE TIGHTNESS TEST RESULTS ON PLATES CLASSED AS HAVING "LIGHT SHRINKAGE" AT A THICKNESS OF ONE INCH*

Plate No.	Plate Thickness, Inches							
	1		3/4		1/2		1/4	
	X-Ray Appearance	Pressure Tightness	X-Ray Appearance	Pressure Tightness	X-Ray Appearance	Pressure Tightness	X-Ray Appearance	Pressure Tightness
R11-5 1	LS	HP	MS	HP	MS	HP	MS	L
R11-4 2	LS	HP	LS	HP	LS	HP	LS	HP
R7-4 3	LS&T	HP	MS	HP	MS	L	--	--
R4-3 4	LS	HP	LS	HP	MS	L	--	--
R5-4 5	LS	HP	LS	HP	LS	HP	LS	L
R11-1 6	LS&T	HP	LS&T	HP	LS&T	HP	LS	HP
R12-1 7	LS	HP	LS	HP	LS	HP	MS	HP
R12-4 8	LS	HP	MS	HP	MS	HP	MS	HP
R21-2 9	LS	HP	MS	HP	MS	HP	MS	HP
R29-2 10	LS	HP	LS	HP	LS	HP	MS	L
R10-2 11	LS&T	HP	LS&T	HP	LS&T	L	--	--
R11-2 12	LS	HP	CS	L	--	--	--	--
R11-3 13	LS	HP	LS	HP	LS	HP	LS	L
R23-1 14	LS&T	L	--	--	--	--	--	--

* CODE: LS = Light shrinkage.
MS = Medium shrinkage.
CS = Concentrated shrinkage.
HP = Held pressure.

L = Leaked.
T = Tear.

TABLE 2

RADIOGRAPH AND PRESSURE TIGHTNESS TEST RESULTS ON PLATES CLASSED AS HAVING "MEDIUM SHRINKAGE" AT A THICKNESS OF ONE INCH*

Plate No.	Plate Thickness, Inches							
	1		3/4		1/2		1/4	
	X-Ray Appearance	Pressure Tightness	X-Ray Appearance	Pressure Tightness	X-Ray Appearance	Pressure Tightness	X-Ray Appearance	Pressure Tightness
R10-4 1	MS & T	L	--	--	--	--	--	--
R7-6 2	MS	HP	MS	L	--	--	--	--
R21-1 3	MS & T	L	--	--	--	--	--	--
R11-6 4	MS	HP	MS	HP	MS	HP	HS	L
R4-1 5	MS	HP	MS	HP	MS	L	--	--
R46-2 6	MS	HP	MS	HP	MS	HP	MS	L
R25-1 7	MS & T	L	--	--	--	--	--	--
R19 8	MS & T	HP	MS	HP	MS	HP	MS	HP
R15 9	MS	HP	MS	L	--	--	--	--
R7-5 10	MS	HP	CS	HP	CS	L	--	--
R7-3 11	MS	HP	MS	HP	MS	L	--	--
R-2 12	MS	HP	LS	HP	LS	L	--	--
R7-7 13	MS	L	--	--	--	--	--	--
R-1 14	MS	HP	MS	L	--	--	--	--
R-39 15	MS	HP	MS	HP	MS	HP	MS	L
R-28 16	MS & T	L	--	--	--	--	--	--
R-4 17	MS	HP	MS	HP	LS	HP	LS	HP
R18-1 18	MS	HP	HS	HP	HS	L	--	--
R-3 19	MS & T	HP	LS & T	HP	LS	HP	LS	HP
R42-2 20	MS	HP	MS	HP	MS	HP	MS	L

*CODE: LS = Light Shrinkage, MS = Medium Shrinkage, CS = Concentrated Shrinkage, HP = Held Pressure, HS = Heavy Shrinkage. L = Leaked. T = Tear.

TABLE 3

RADIOGRAPH AND PRESSURE TIGHTNESS TEST RESULTS ON PLATES CLASSED AS HAVING "CONCENTRATED SHRINKAGE" AT A THICKNESS OF ONE INCH*

Plate No.	Plate Thickness, Inches							
	1		3/4		1/2		1/4	
	X-Ray Appearance	Pressure Tightness	X-Ray Appearance	Pressure Tightness	X-Ray Appearance	Pressure Tightness	X-Ray Appearance	Pressure Tightness
R10-1 1	CS & T	L	--	--	--	--	--	--
R5-3 2	CS & T	L	--	--	--	--	--	--
R6-1 3	CS & T	HP	CS & T	HP	CS & T	L	--	--
R10-3 4	CS	L	--	--	--	--	--	--
R6-2 5	CS & T	HP	CS & T	HP	MS & T	HP	MS & T	L
R6-3 6	CS & T	HP	CS & T	HP	CS & T	L	--	--
R5-1 7	CS & T	L	--	--	--	--	--	--
R12-3 8	CS	HP	CS	HP	CS	HP	CS	L
R6-5 9	CS	L	--	--	--	--	--	--
R7-1 10	CS & T	HP	CS & T	L	--	--	--	--
R7-2 11	CS & T	HP	CS & T	L	--	--	--	--
R5-2 12	CS & T	L	--	--	--	--	--	--
R34 13	HS	HP	MS	HP	MS	HP	MS	L
R17 14	CS & T	L	--	--	--	--	--	--

*CODE: MS = Medium Shrinkage, CS = Concentrated Shrinkage, HS = Heavy Shrinkage, HP = Held Pressure. L = Leaked. T = Tear.

TABLE 4

RADIOGRAPH AND PRESSURE TIGHTNESS TEST RESULTS ON PLATES CLASSED AS HAVING "GAS POROSITY AND SHRINKAGE" AT A THICKNESS OF ONE INCH*

Plate No.		Plate Thickness, Inches							
		1		3/4		1/2		1/4	
		X-Ray Appearance	Pressure Tightness	X-Ray Appearance	Pressure Tightness	X-Ray Appearance	Pressure Tightness	X-Ray Appearance	Pressure Tightness
R23-2	1	MS & GP	HP	MS & GP	HP	MS & GP	HP	MS & GP	L
R27-2	2	MS & GP	HP	MS & GP	HP	MS & GP	HP	MS & GP	HP
R33-2	3	MS & GP	HP	MS & GP	HP	MS & GP	HP	MS & GP	HP
R24-2	4	MS & GP	HP	MS & GP	HP	LS & GP	HP	LS & GP	HP
R33-1	5	MS & GP	HP	MS & GP	HP	MS & GP	HP	MS & GP	HP
R24-1	6	MS & GP	HP	MS & GP	HP	MS & GP	HP	MS & GP	L
R29-3	7	MS & GP	HP	MS & GP	HP	MS & GP	HP	MS & GP	HP
R43-3	8	MS & GP	HP	MS & GP	HP	MS & GP	HP	LS & GP	HP
R23-3	9	MS & GP	HP	MS & GP	HP	MS & GP	HP	MS & GP	HP
R27-3	10	MS & GP	HP	MS & GP	HP	MS & GP	HP	HS & GP	L
R8-1	11	HS & GP	L	--	--	--	--	--	--
R42-4	12	MS & GP	HP	MS & GP	HP	MS & GP	L	--	--
R42-3	13	MS & GP	HP	MS & GP	HP	MS & GP	L	--	--
R9-1	14	HS & GP	L	--	--	--	--	--	--
R42-1	15	HS & GP	HP	MS & GP	HP	MS & GP	HP	MS & GP	HP
R40	16	MS & GP	HP	LS & GP	HP	LS & GP	HP	LS & GP	HP
R27-1	17	MS & GP	L	--	--	--	--	--	--
R43-2	18	HS & GP	HP	MS & GP	HP	MS & GP	HP	MS & GP	L
R44	19	MS & GP	HP	HS & GP	L	--	--	--	--
R24-3	20	MS & GP	HP	MS & GP	HP	MS & GP	HP	MS & GP	HP
R33-3	21	HS & GP	HP	HS & GP	HP	HS & GP	L	--	--
R38	22	HS & GP	HP	HS & GP	HP	HS & GP	L	--	--

*CODE: LS = Light Shrinkage, MS = Medium Shrinkage, HS = Heavy Shrinkage, GP = Gas Porosity, HP = Held Pressure. L = Leaked. No concentrated porosity. No tears.

THE PRESSURE TESTS

A special jig shown in Figure 1 was made to hold the plates during the pressure tests. With this apparatus, an hydraulic pressure of 250 lbs per square inch was applied to one side of a plate and held constant for fifteen minutes. This pressure and time exceed those usually used in tests made on bronze castings. Air pockets immediately under the plate were avoided by holding the plate at an angle of three or four degrees to the horizontal, to allow the air to leak through the rubber gasket before the clamps were tightened and maximum hydraulic pressure applied.

RADIOGRAPHY

The radiographs of the one-inch section were taken with 220 KV and ten milliamperes with an exposure time of five minutes and a 36 inch target-to-film distance. A lead filter 0.03 inch in thickness was used at the source and lead intensifying screens 0.005 inch in thickness were placed on both sides of Eastman Type F X-ray film. The voltage of the 220 KV unit was decreased with decreasing thickness in order to obtain maximum contrast and only 180 KV was used at the thinner sections. No changes were made in the other

conditions of the radiographic procedure, and with a density of 1.25 the sensitivity was usually about one percent.

Figures 2 to 5 illustrate typical nonuniformities found in the one inch sections in pressure tight castings. With the exception of casting R6-2 shown in Figure 4, all of these castings held pressure in the one-quarter-inch section. This particular casting (R6-2) leaked only when the thickness was reduced to one quarter inch.

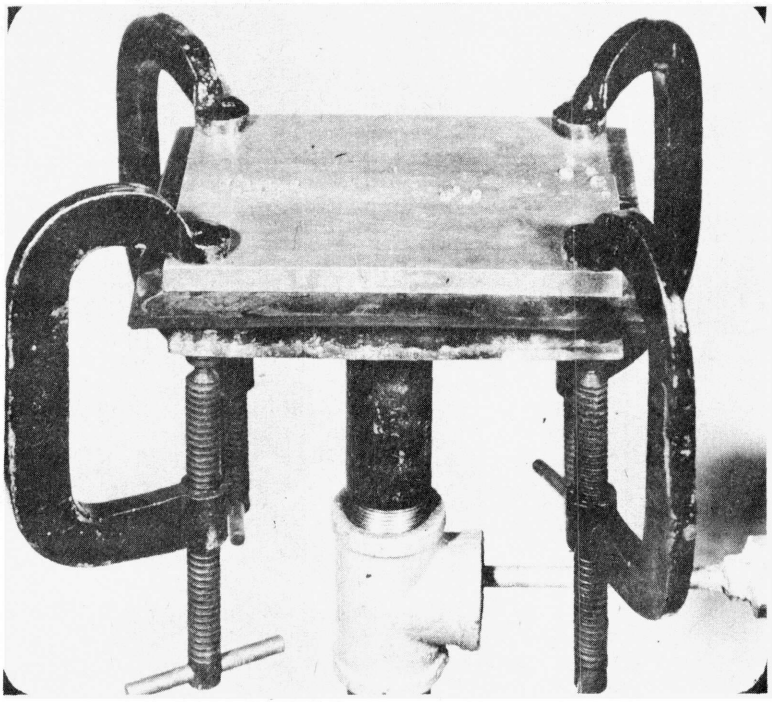

Fig. 1 - Pressure Testing Apparatus

Nonuniformity	Plate No.
Light Shrinkage	Figure 2, R11-4
Medium Shrinkage	Figure 3, R-3
Concentrated Shrinkage	Figure 4, R6-2
Shrinkage and Gas Porosity	Figure 5, R24-3

Every radiograph that is described in Tables 1 to 4 inclusive has been kept for reference and will be available for a period of one year from date of this report for examination at the Naval Research Laboratory. Since wide variations existed in each of the four classifications of nonuniformities there is a tendency for some types to overlap.

DISCUSSION OF RESULTS

Considerable difficulty was encountered in producing a single type of nonuniformity in the plates. It will be noted in the tables that light and medium shrinkage were frequently associated with tears. Similarly, gas porosity often had shrinkage as an accompanying nonuniformity.

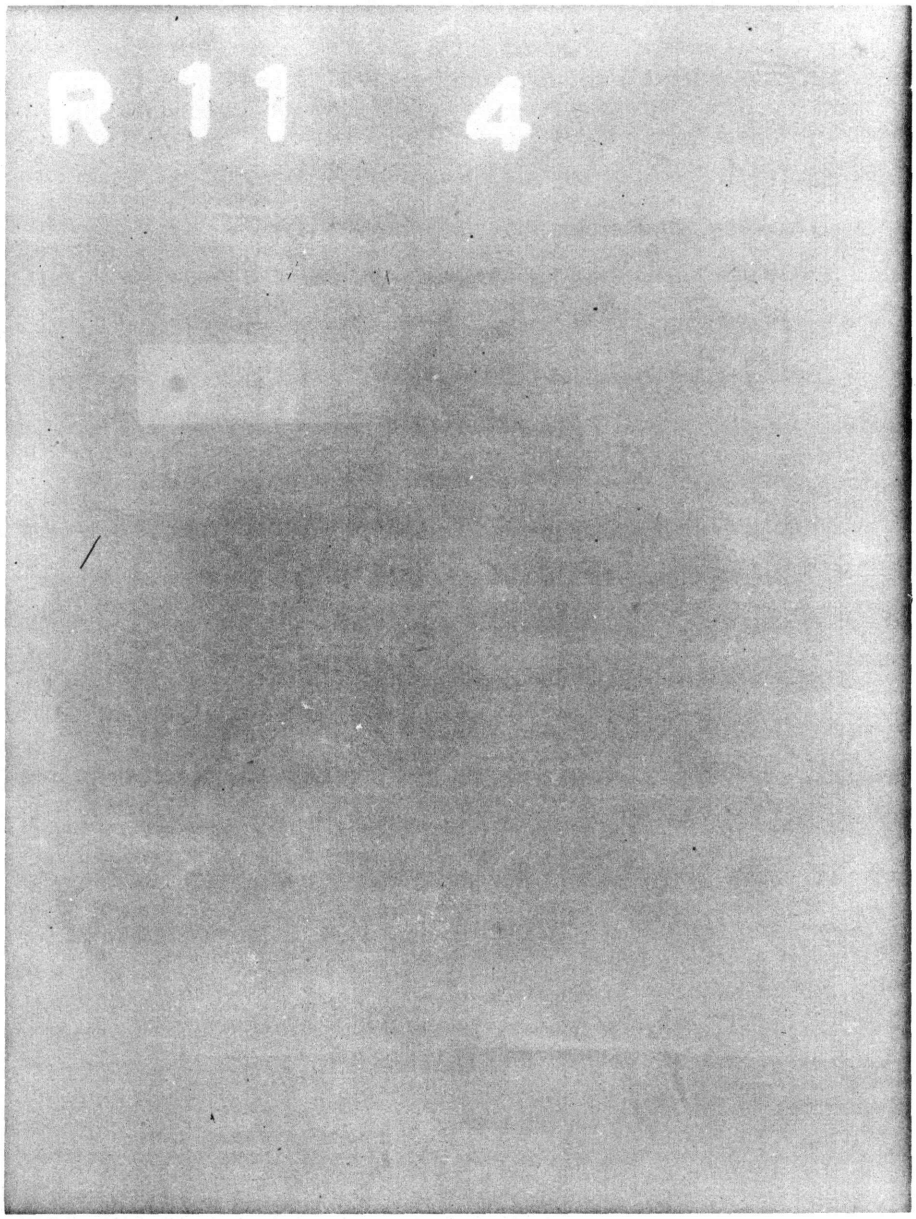

Fig. 2 - Light Shrinkage - Pressure Tight

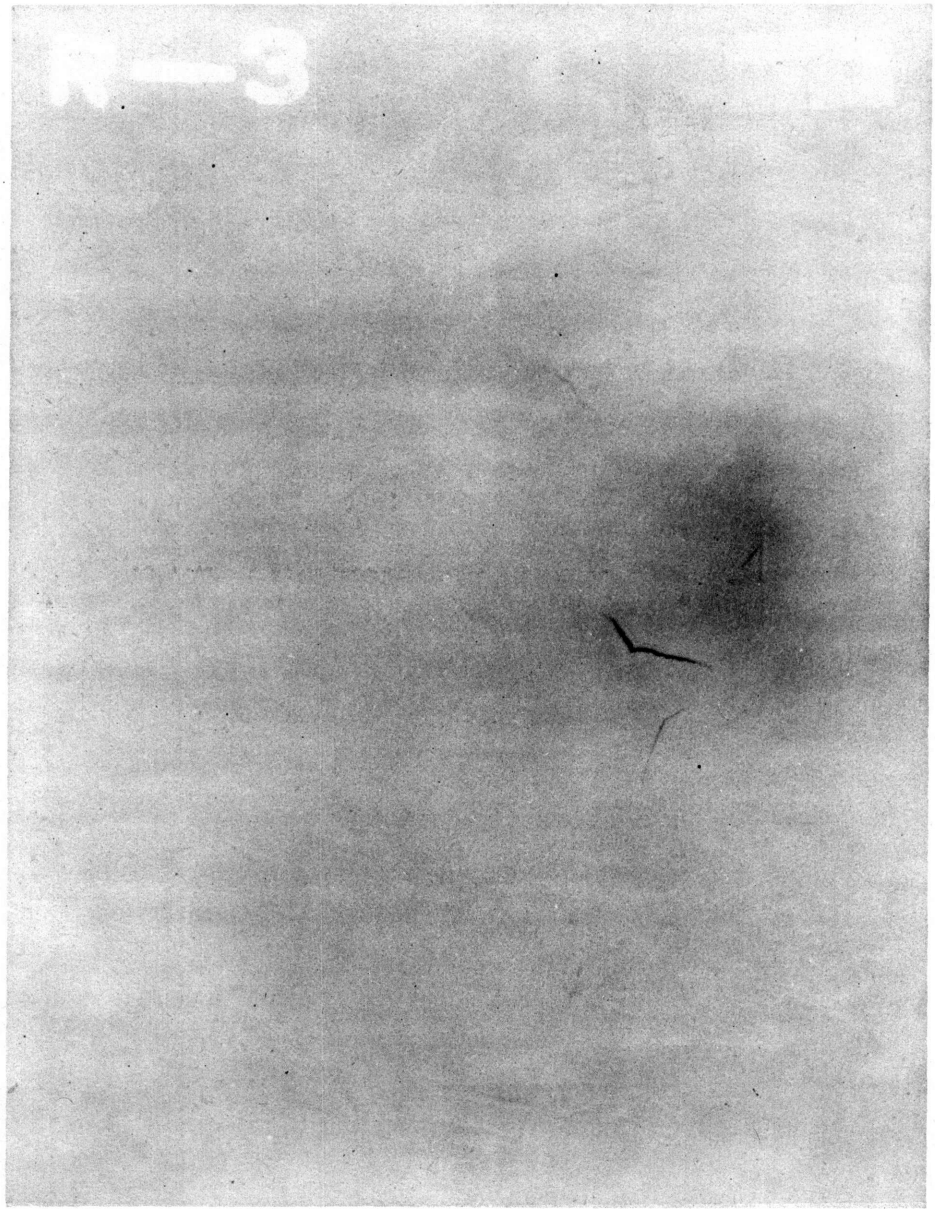

Fig. 3 - Medium Shrinkage - Pressure Tight

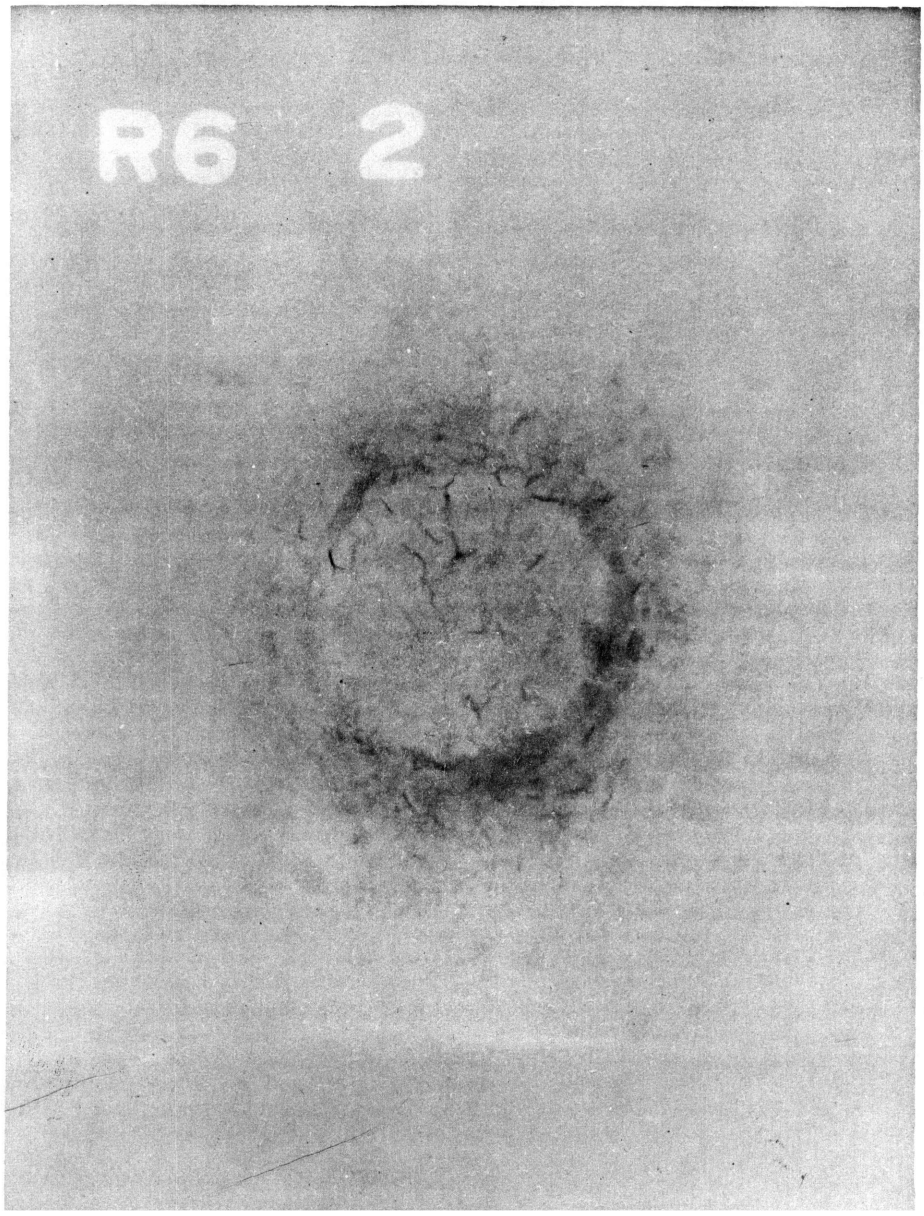

Fig. 4 - Concentrated Shrinkage - Leaked at 1/4 Inch

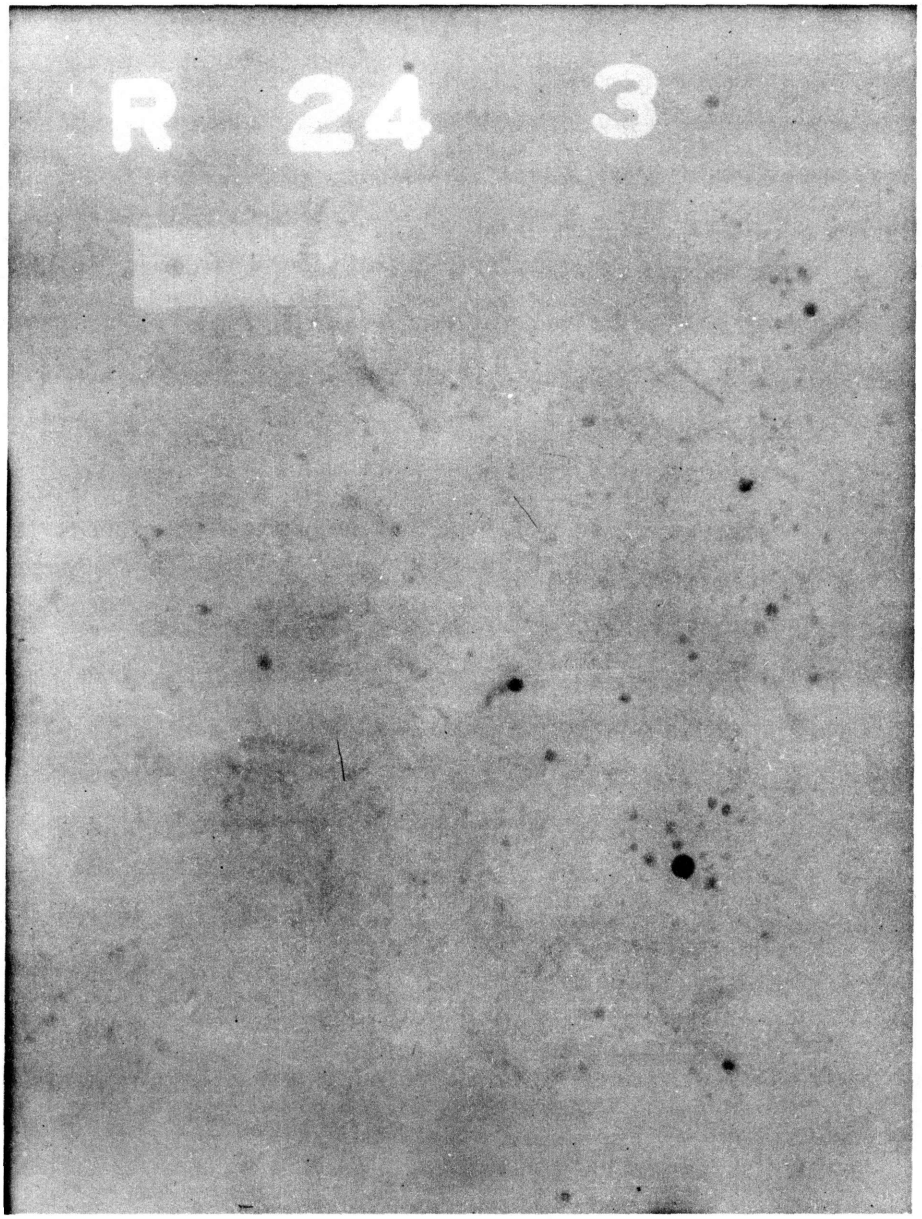

Fig. 5 - Shrinkage and Gas Porosity - Pressure Tight

Light Shrinkage

Several noteworthy observations regarding radiography of plates with light shrinkage may be made from Table 1. It will be seen that only one of the castings leaked when tested in the one-inch section. Considering the number of castings that leaked at various thicknesses, approximately two-thirds of them were not pressure tight even though the shrinkage was very light. The interpretation of radiographs showing light shrinkage in the one-inch section is difficult because the shrinkage may be concentrated, as is shown by the change in description to "medium shrinkage" in many of the radiographs of the thinner sections. The interpretation was made more difficult since concentration of shrinkage was not necessarily indicative of failure in the pressure test. Of the five quarter-inch sections that held pressure, three did so in spite of medium shrinkage.

Medium Shrinkage

Only five of the twenty plates in the category "medium shrinkage" showed initial leakage. After the remaining castings had been machined to thinner sections, their soundness was much more impaired. Only three held pressure at one-quarter inch thickness and in two of these the shrinkage was then classified as light. It can be said qualitatively, by comparing Tables 1 and 2, that the more severe the shrinkage, the less the pressure tightness.

Concentrated Shrinkage

Seven of the fourteen one-inch castings showing concentrated shrinkage were not pressure tight (Table 3). The seven remaining castings failed at some thinner section. This indicates that concentrated shrinkage is the most serious kind of shrinkage. Radiography appears to be a very desirable method of inspection for castings with this type of nonuniformity.

Shrinkage and Gas Porosity

Several outstanding characteristics of gas porosity are evident from Table 4. First, leakage occurred in the one-inch plates to about the same extent as it did with light shrinkage. Second, a higher proportion of the plates held pressure in the quarter-inch section than in any other set of experiments. Third, there was fairly uniform distribution of the gas porosity and accompanying shrinkage. In very few instances did the intensity of the porosity change from the designation in the one-inch section. This category of nonuniformity is distinguished by the absence of tears and concentrated shrinkage.

Tears

One of the most serious types of defect is probably the hot tear. This defect almost always occurs with other defects and can not easily be separated into a special category. Although as shown in Table 2, tears may occasionally be superficial, it is believed that even minute tears present a strong basis for rejection of gun metal castings.

Significance of Radiography of Gun Metal Castings

If radiographs of gun metal castings are free of any indications of nonuniformities the castings should be pressure tight. If, however, there are indications of nonuniformities,

even though they are slight, the possibility of leakage exists. The fact that a radiograph indicates a slight nonuniformity is not a valid reason for assuming that the damage to the casting is in proportion to the severity of the nonuniformity, as will be understood by an inspection of Figures 2 to 5. This type of nonuniformity is very important.

CONCLUSIONS

1. Gun metal castings showing light shrinkage in a radiograph are of questionable acceptability.

2. Radiographs showing medium shrinkage or gas porosity in combination with shrinkage indicate a serious condition and greater possibility of leakage under pressure.

3. There is little question about radiographs of castings that have concentrated shrinkage or tears. These are the most dangerous types of nonuniformities and are sufficient reason for rejecting castings.

4. Castings intended for critical use should be radiographed as well as pressure tested.

APPENDIX

Mechanical Properties of Some Defective Bronze Castings

Selected plates that leaked in the one-inch section were used for standard 0.505-inch diameter tensile specimens machined from sections containing defects. The test specimens were selected so that each specimen showed a difference in the degree of severity of the defect. The positions from which tensile test specimens were taken are shown by white lines on the radiographs, Figures 6 to 9.

Nonuniformity	Plate No.
Light Shrinkage	Figure 6, R4-4
Medium Shrinkage	Figure 7, R7-7
Concentrated Shrinkage	Figure 8, R6-5
Shrinkage and Gas Porosity	Figure 9, R9-1

These are four typical radiographs corresponding to the four classifications given in the main part of this report. The test coupons were taken over the greatest gradation of nonuniformity found. The tensile test specimens were subjected to visual examination with the naked eye and also with a 32 mm microscopic lens after machining. They were pulled at a rate of 0.05 inch per minute. The percentage of discoloration of the fracture and the type of fracture was noted with each specimen. The results of the mechanical tests are given in Table 5.

As would be expected, mechanical properties of unsound bronze castings are far below the requirements for gun metal. The results given in Table 5 are typical of data taken from ten plates that were investigated. The tensile strength of a sound plate might be four to five thousand psi below specification, but certainly not 20,000 psi below, as was found in many of the castings. It was not possible to find characteristic effects of the various types of nonuniformities on the mechanical properties. There is fairly good agreement however between severity of defect estimated by radiography and the damage to mechanical properties.

TABLE 5

EFFECT OF SHRINKAGE ON MECHANICAL PROPERTIES OF GUN METAL

Plate No.	Position of Test Bar in Plate	Tensile Strength per sq in.	Percent Elongation	Fracture Appearance
		Light Shrinkage		
R4-4	1	35100	29	100% woody
	2	23900	12	50% woody, 50% dark oxide
	3	24000	10	50% woody, 50% dark oxide
	4	27250	15	80% woody, 20% dark oxide
		Medium Shrinkage		
R7-7	1	28500	27	35% woody, 65% dark oxide
	2	29400	B.O.	35% woody, 65% dark oxide
	3	31500	20	50% reddish-grey, 50% dark oxide
	4	28750	20	85% grey, 15% reddish-yellow
		Concentrated Shrinkage		
R6-5	1	11400	--	5% woody, 95% black oxide
	2	10200	--	5% woody, 95% black oxide
	3	20500	15	25% woody, 75% black oxide
	4	28000	21	50% woody, 50% black oxide
		Heavy Shrinkage and Gas Porosity		
R9-1	1	32700	22	50% light brown, 50% grey
	2	21100	--	40% woody, 60% light red oxide
	3	22200	--	30% grey, 70% red oxide
	4	26500	15	20% woody, 80% dark oxide

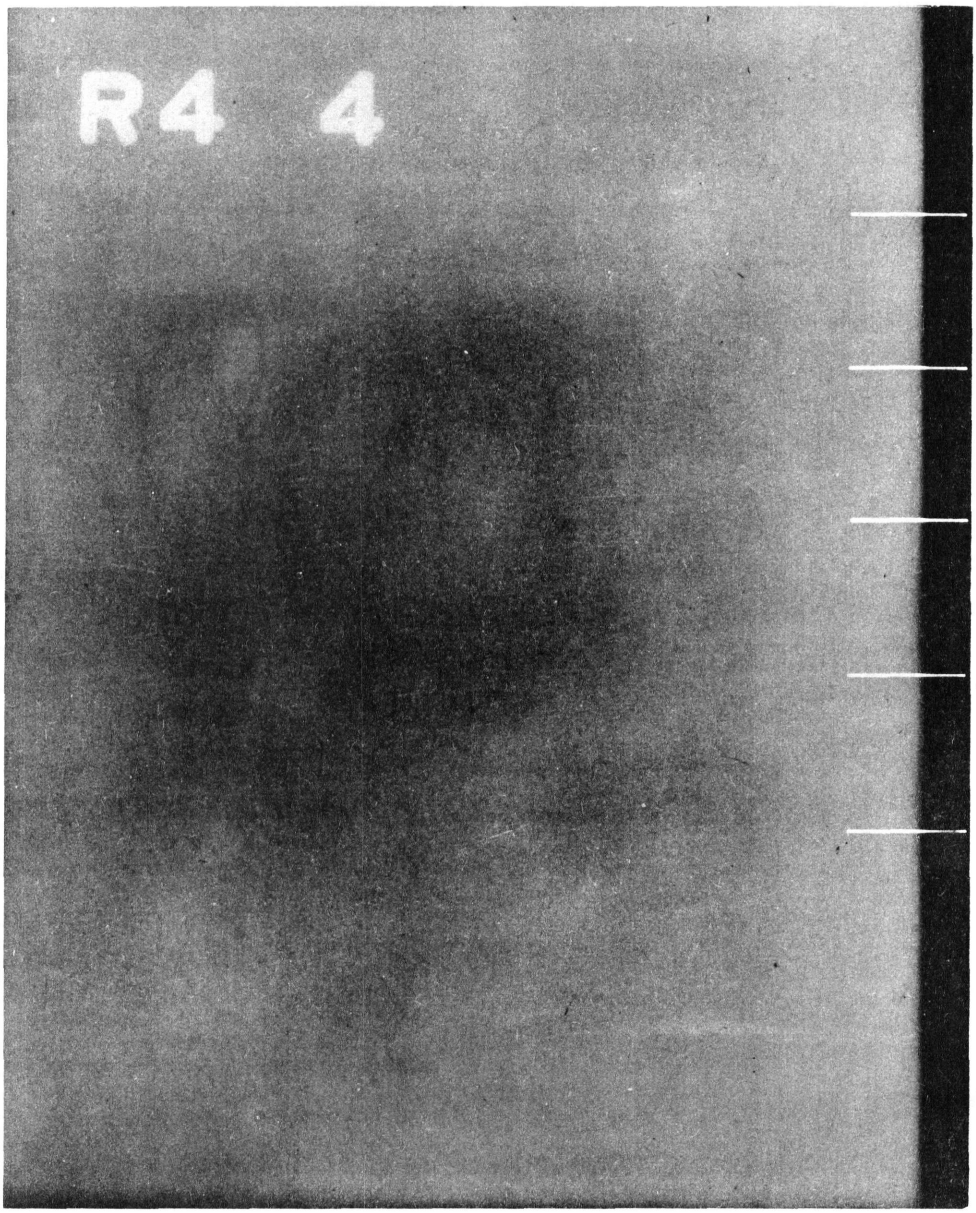

Fig. 6 - Light Shrinkage - Leaked at 1/4 Inch

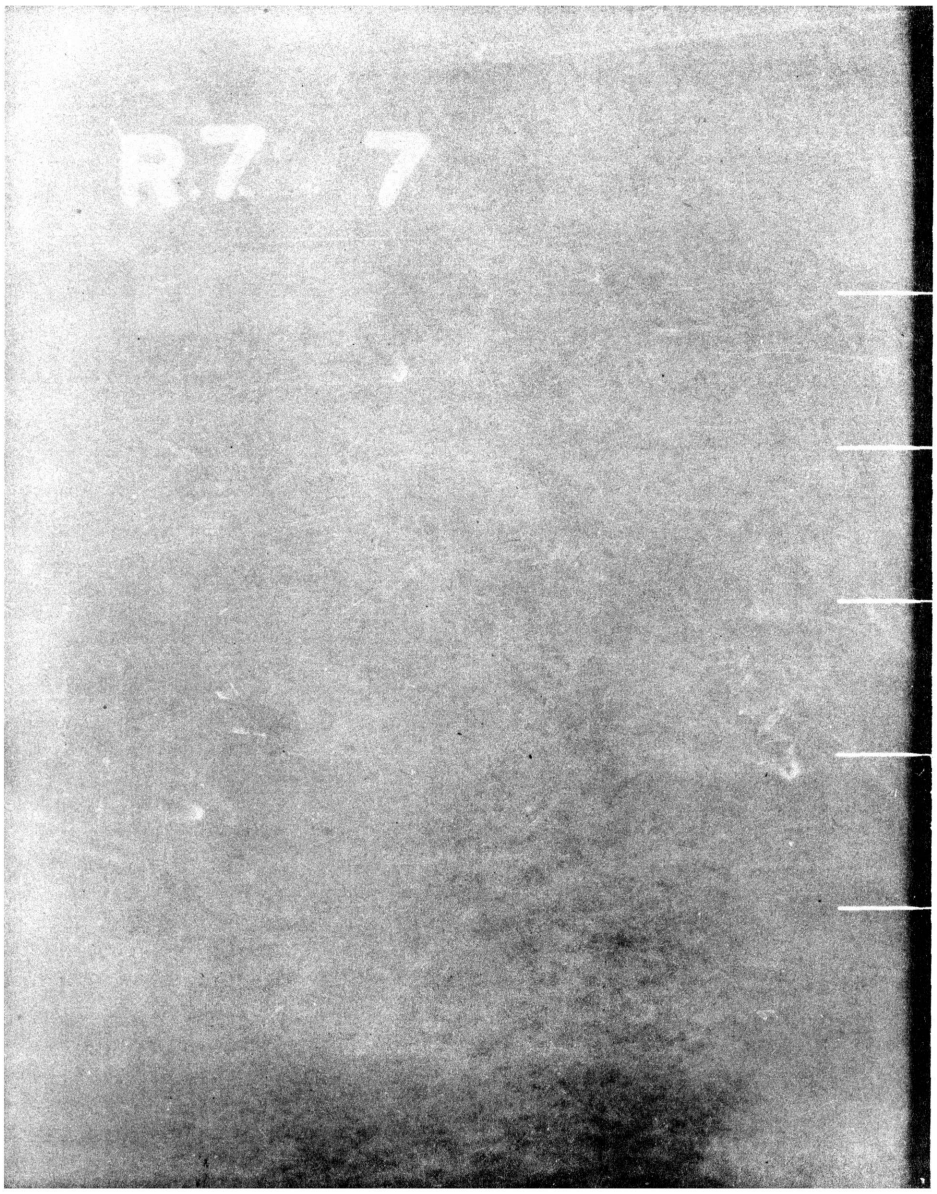

Fig. 7 - Medium Shrinkage - Leaked at One Inch

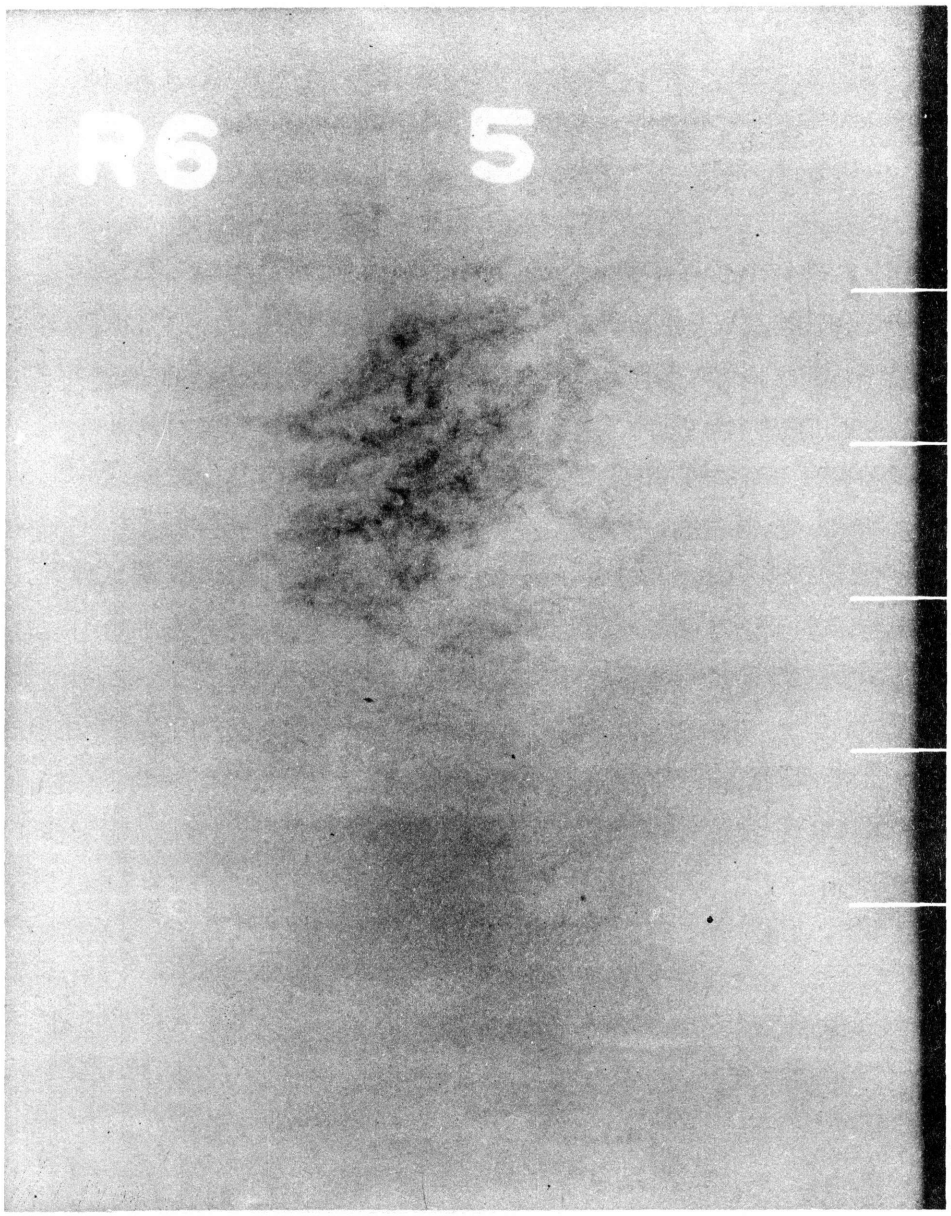

Fig. 8 - Concentrated Shrinkage - Leaked at One Inch

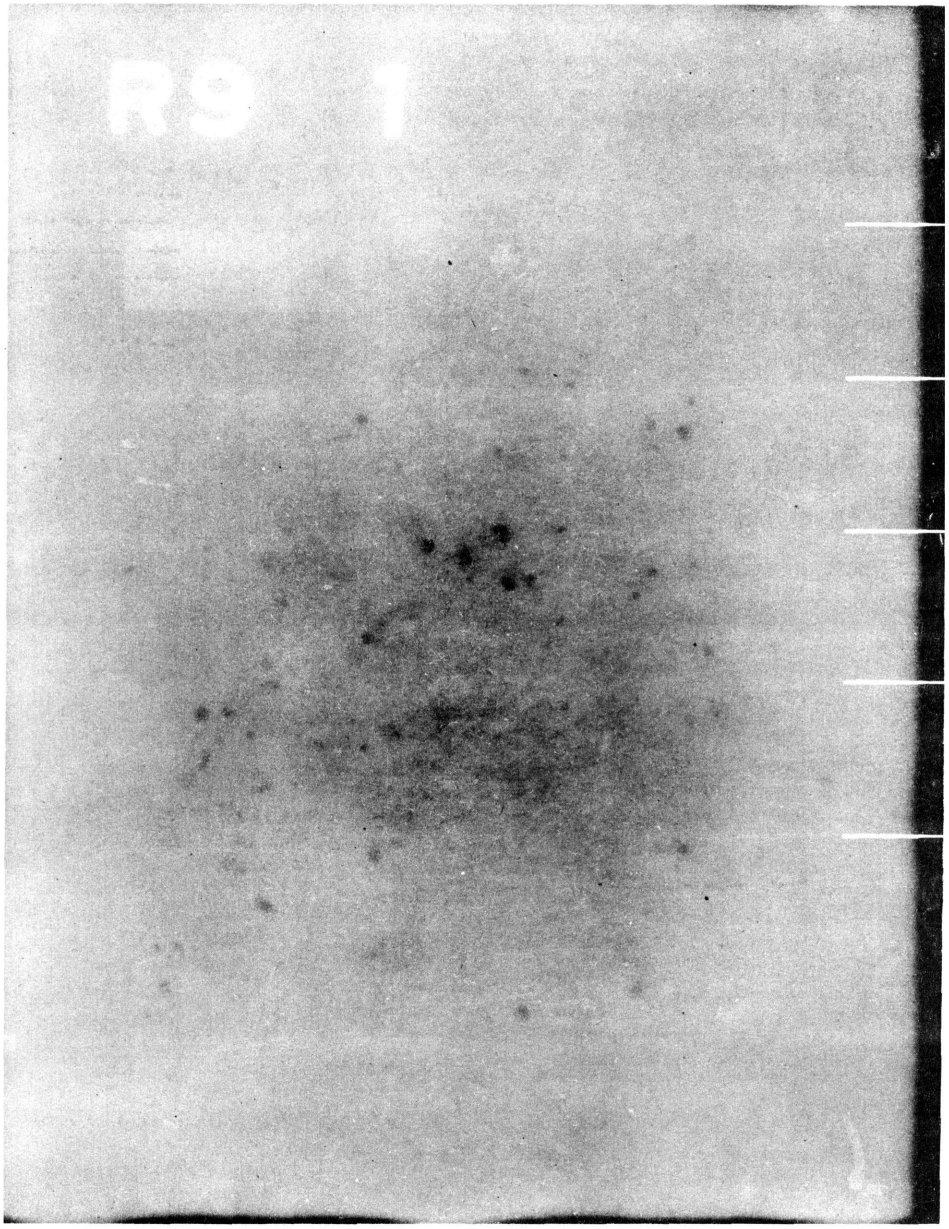

Fig. 9 - Shrinkage and Gas Porosity - Leaked at One Inch