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X-Ray Inspection of Castings (Army Air Forces' Requirements)

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The author contributed a brief account of the radiographic practices necessary to comply with government specifications to a round table discussion on inspection methods at the last ⊕ Convention, and later was able to release for publication in Metal Progress a full set of the radiographic standards set up about a year ago to govern acceptance of structural castings for airplanes. Representative negatives are reproduced in this article. Those eliminated are either of similar defects which did not register strong enough to appear on an engraving without retouching, or of defects readily observed by visual inspection without X-ray.

X-RAY INSPECTION OF CASTINGS

(ARMY AIR FORCES' REQUIREMENTS)

By ROBERT KATZ
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TOWARDS the end of 1941 it became imperative that general standards for the acceptance of aircraft castings be established. At that time the commercial standards for the acceptance or rejection were largely intangible; castings rejected by one radiographic laboratory were later accepted by another. As a check on the validity of commercial X-ray inspection, rejected castings were subjected to breakdown or tensile tests conducted upon specimens machined from castings, and many were found to have strengths considerably in excess of design or specification values. Pressure of increased aircraft production made such a waste of material intolerable. As remarked at the outset it became necessary to establish an inspection procedure which would insure that:

1. No casting which might fail would find its way into an airplane structure.
2. A minimum number of usable parts would be discarded by unnecessarily rigid inspection standards, and
3. The inspection procedure be as economical of manpower and materials as was consistent with the first two aims.

To achieve these ends, a procedure for the X-ray examination of *structural* castings which attempted to resolve these principles was adopted by the Army Air Forces in February, 1942. An outline of the procedure and some representative radiographs will be given, principally applicable to sand and permanent mold castings of aluminum or magnesium alloys used in the airplane's structure. Castings for use in hydraulic systems need not be X-rayed if they are hydrostatically tested unless sections of these castings are also subject to structural loads, whereupon such *sections* are subject to the same requirements as structural castings.

Allowable Stress — In the design an allowable stress is permitted of half the minimum specified ultimate strength, as determined on separately cast test bars. Castings may be designed for no X-ray inspection provided that ultimate design loads will not produce stresses in excess of 20% of the allowable stress (10% of minimum test bar strength) and such castings are known as Class B castings. Castings designed so that the ultimate design loads produce stresses between 20 and 100% of the allowable stress are called Class A castings, and must be radiographically examined and statically tested as outlined below:

Test Lot — Once preliminary design and foundry development have been completed, and production pattern equipment has been prepared, a test lot, consisting of the first 100 castings of the first production run of each Class A design, must be 100% X-ray inspected with special reference to stressed sections. The three worst castings of this test lot, as graded by the radiographs, are then machined and tested so as to simulate the loading of the castings as installed in the airplane. Radio-

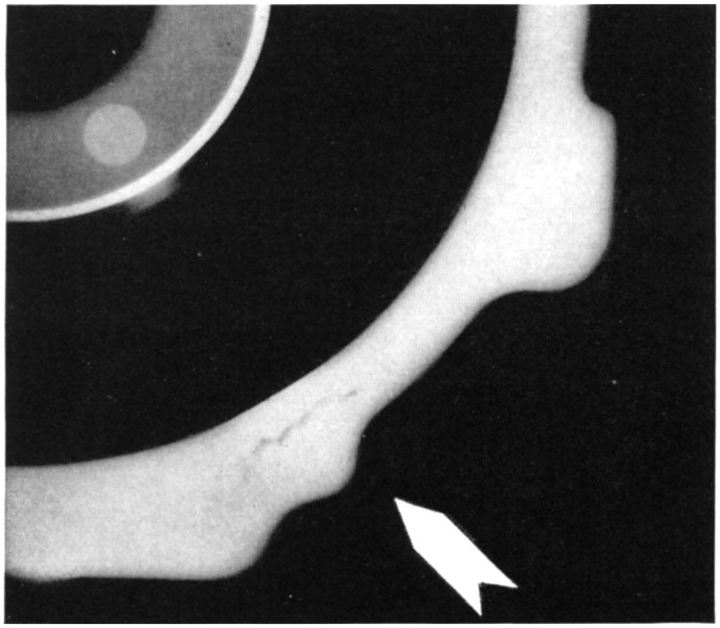


Fig. 1 (Radiograph No. 3 of Standard Set) Shows a Shrinkage Cavity in an Aluminum Alloy Permaent Mold Casting; Not Acceptable

graphs of the three test castings become acceptance standards for all other castings of the same design, if the weakest casting withstands a test load of 1.5 times the design load (1.25 times for steel centrifugal castings).

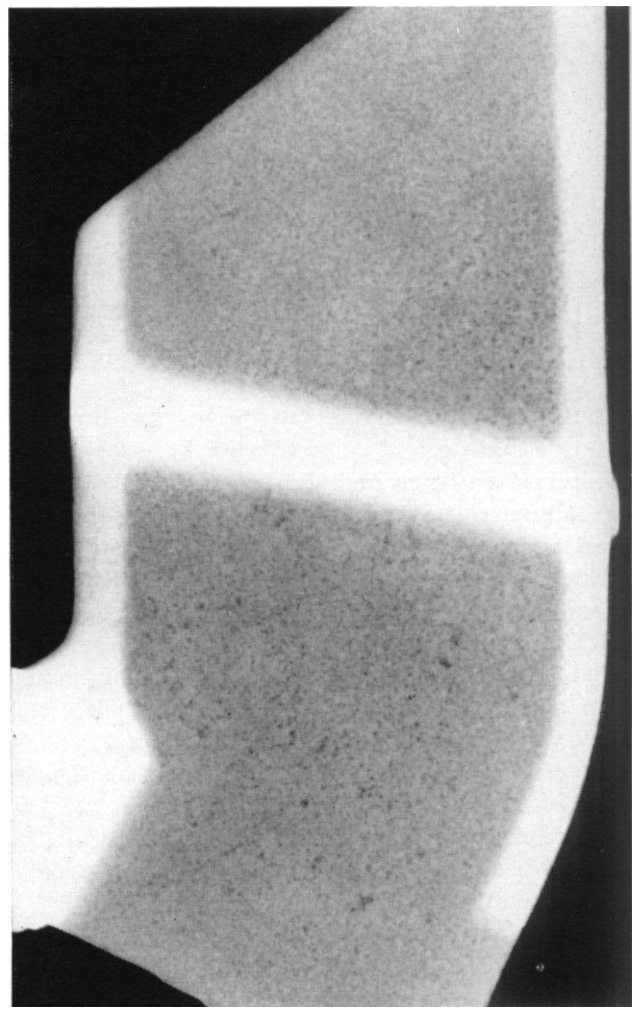
Should the test castings prove too weak, sounder castings may be selected from the test lot until satisfactory radiographic standards are obtained.

The Army inspector may reduce the size of the test lot for complicated castings which are expensive to radiograph. Where fewer than 100 castings are required of a particular Class A design, the entire lot of castings constitutes the test lot, but only one need be statically tested.

In the course of production, casting quality may vary sufficiently from the test lot so that a revision of the X-ray standards is desirable. The contractor may revise these standards at his option by repeating the X-ray and static test procedure upon any group consisting of 100 consecutive production castings.

Production Runs — Lots subsequent to the test lot are radiographically inspected on a percentage basis according to the ratio of test loads and design loads of the weakest of the test castings. Where this ratio lies between 1.5 and 3.0 (1.25 and 3.0 for steel centrifugal castings), all castings in the order or production run are given 25% inspection and are called Class A-1. Class A-2 castings are those in which the ratio of test to design loads lies between 3 and 10, and receive 10% inspection. Where the ratio is greater than 10, castings receive no X-ray inspection and are called Class A-3. When 1% of the original sampling (the 25% for Class A-1, or the 10% for Class A-2) is found inferior to the standards, 100%

Fig. 2 (Radiograph No. 10 of Standard Set) Shows Generally Distributed Gas Porosity in an Aluminum Alloy Sand Casting, Which Is Undesirable, but Acceptance or Rejection Would Be Based Upon the Static Test



inspection of the balance of the lot may be required.

Substandard A-1 castings are rejected, but substandard A-2 castings are placed in salvage. Castings whose defects cannot be judged from the standard radiographs are similarly placed in salvage. Castings which receive no X-ray inspection are subject to visual inspection.

Illustrative Radiographs

In addition to the requirements of static test, no Class A casting is acceptable which contains defects of a localized, stress raising type. Thus cracks, cold shuts, misruns, shrinkage voids (Fig. 1) are automatic cause for rejection. [EDITOR'S NOTE: Cracks, cold shuts and misruns are all readily found by visual inspection, and the radiographs in the standard set of 17 that show them are not reproduced on these pages, in the interest of saving space.] Defects of a general type which do not act as stress raisers are considered undesirable, but are judged solely on the basis of the static test simulating the working loads on the complete part, as previously outlined. Such defects include gas porosity (Fig. 2 and 3), blowholes (Fig. 4), segregation (Fig. 4), microshrinkage (Fig. 5 and 6), dross and sand inclusions (Fig. 7) and mottling (Fig. 8). Defects of a general type which are so aligned as to cause stress concentration are immediate cause for rejection (Fig. 9).

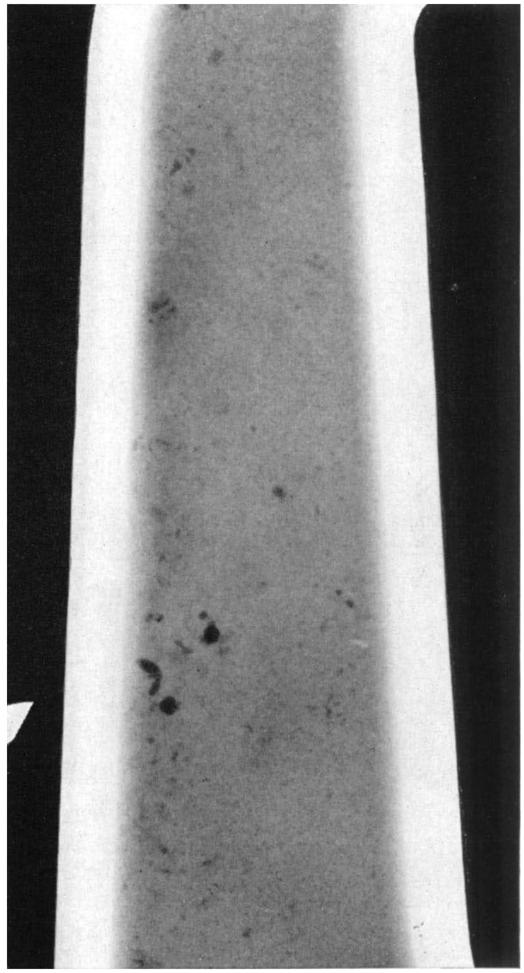


Fig. 4 (Radiograph No. 16 of Standard Set) Shows Round Blowholes and Irregular Segregates in an Aluminum Alloy Sand Casting, Which Are Undesirable, but Acceptance or Rejection Would Be Based Upon the Static Test

Certification of Laboratories — The commercial radiography of Army aircraft castings has been restricted to an approved list of certified laboratories. Certification is set up on the basis of a simple test which requires a laboratory to prepare radiographs of a set of six castings equal to radiographs previously prepared at Wright Field. The required positioning is specified so that direct comparison of the quality of the X-ray films can be made. At this writing about 40 laboratories scattered throughout the United States have been approved. A laboratory failing the first test will be re-tested upon application. Certification may be withdrawn when radiography in production fails to meet Army Air Forces requirements. Thus, each production radiograph must bear the clearly defined image of the applicable penetrameter sensitivity gage.

Certification simply permits an organization to take X-ray pictures, but does not authorize the laboratory to

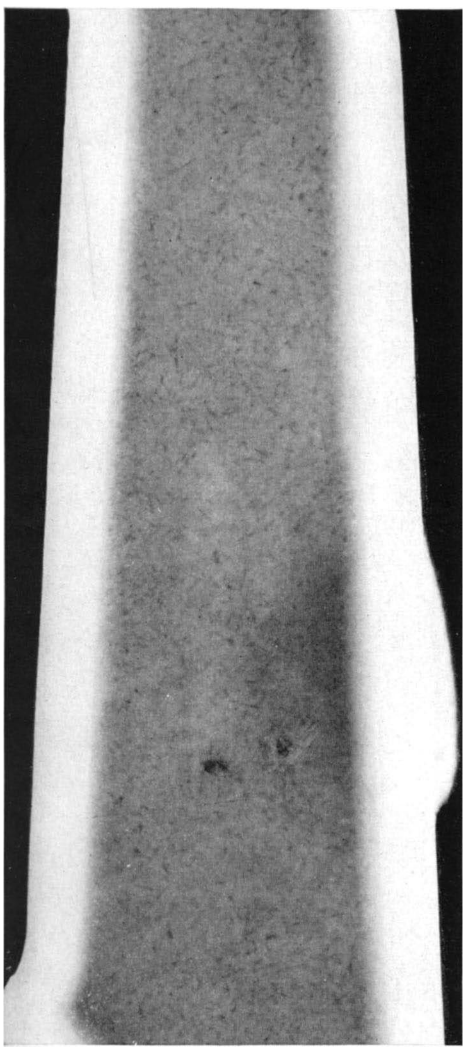


Fig. 3 (Radiograph No. 11 of Standard Set) Shows Elongated Gas Porosity in an Aluminum Alloy Sand Casting, Which Is Undesirable, but Acceptance or Rejection Would Be Based Upon the Static Test

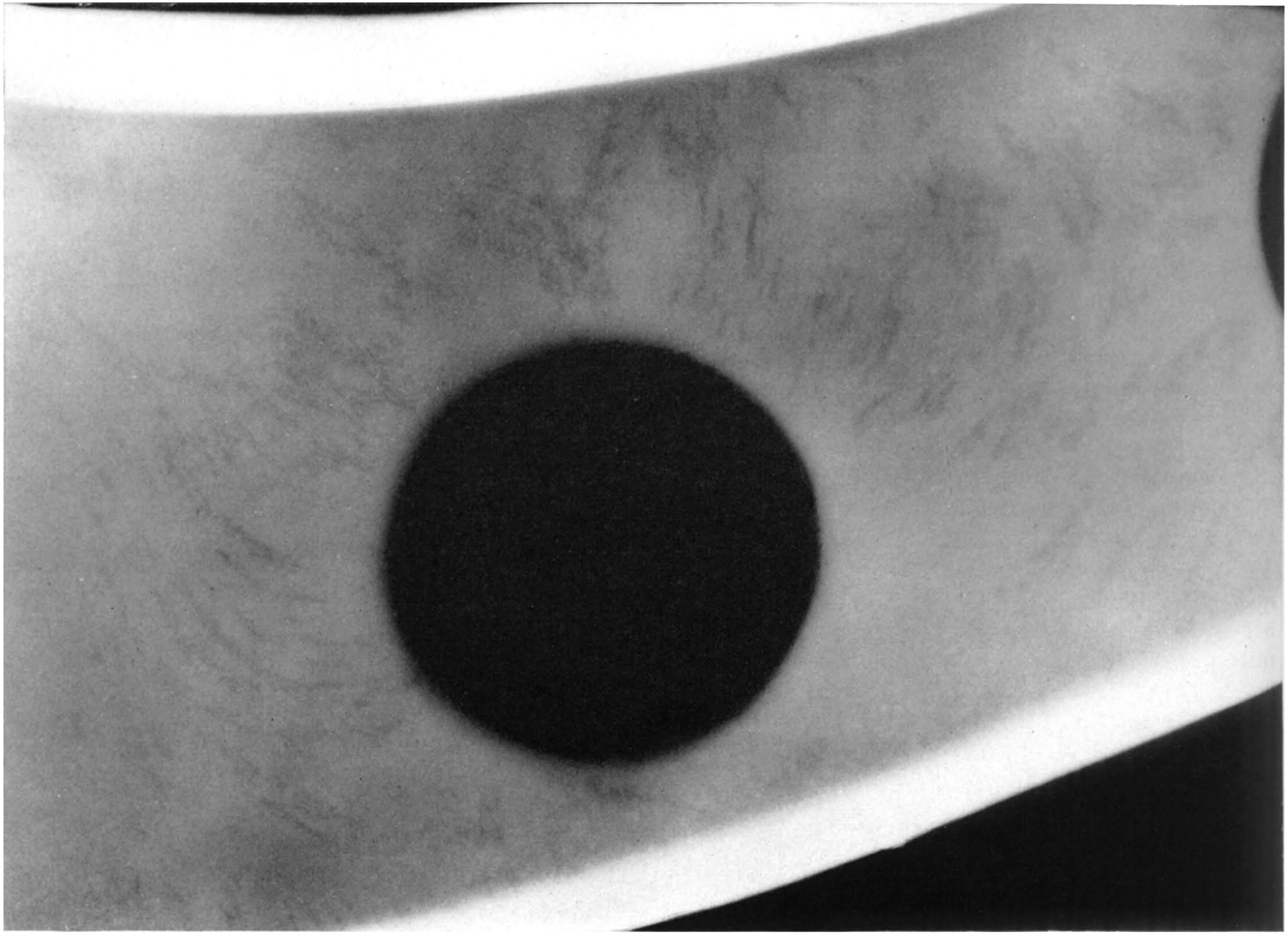


Fig. 5 (Radiograph No. 12 of Standard Set) Shows Feathery Microshrinkage in a Magnesium Alloy Sand Casting, Which Is Undesirable, but Acceptance or Rejection Would Be Based Upon the Static Test

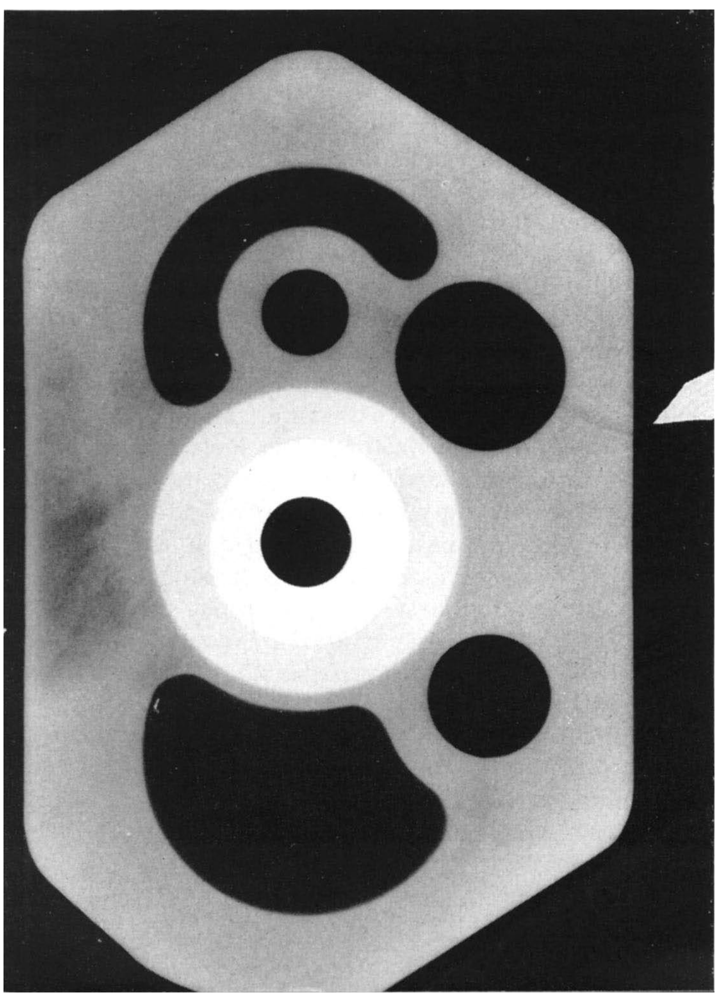


Fig. 6 (Radiograph No. 2 of Standard Set) Shows a Magnesium Alloy Sand Casting With an Accumulation of Microshrinkage at Left, Which Is Undesirable, and a Crack at Right, Which Is Not Acceptable

Fig. 7 (Radiograph No. 17 of Standard Set) Shows Dross and Sand Inclusions in an Aluminum Alloy Sand Casting, Which Is Undesirable, but Acceptance or Rejection Would Be Based Upon the Static Test

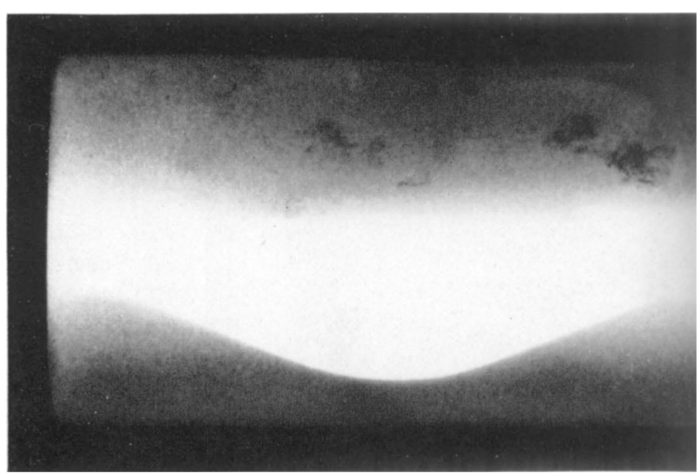
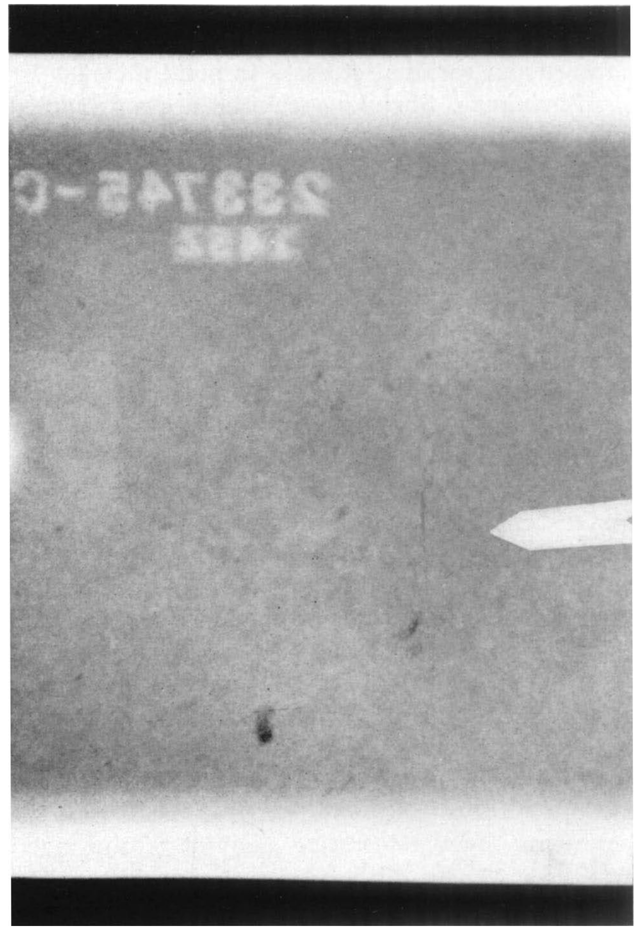


Fig. 8 (Radiograph No. 1 of Standard Set) Shows a Crack Which of Course Is Not Acceptable. It also shows "mottling" throughout the web of this aluminum alloy sand casting which is not a cause for rejection. [Editor's Note: — Mottling always appears as the casting temperature rises, and is therefore to be expected in castings of large size or complexity.]



accept or reject castings. Responsibility for structural castings, as well as for all parts of the airplane, rests with the prime contractor (the airplane manufacturer). The laboratory may not accept or reject castings for the prime contractor unless authorized in writing by the prime contractor, and a copy of the document furnished the Army inspector.

Terminology — Radiographic inspection has been much confused by the absence of a uniform, precisely defined terminology for the markings appearing on the radiograph. The same defect has been described as "gas porosity", "pinholing", "wormholing" and "pepper and salt porosity". The following definitions of various discontinuities have therefore been adopted:

Cracks are represented by darkened lines of variable width which are dendritic when caused

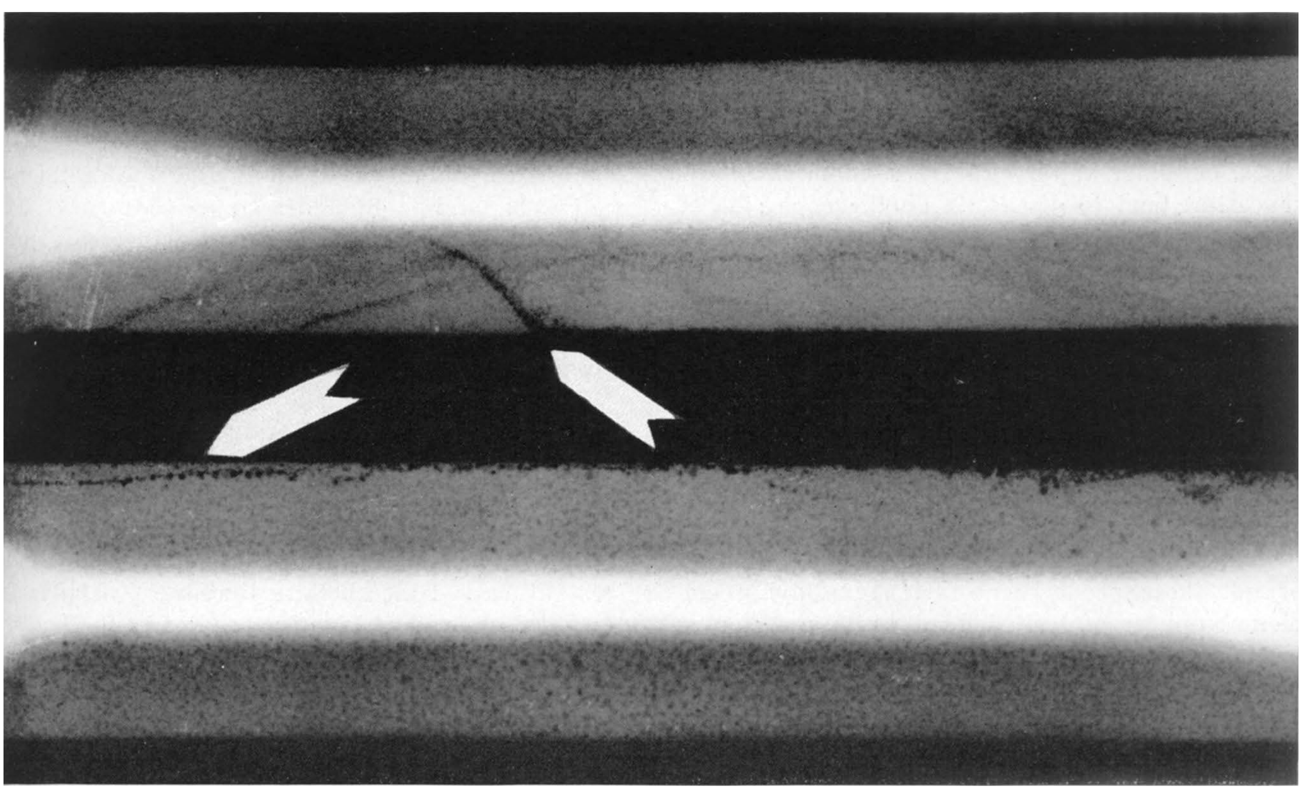


Fig. 9 (Radiograph No. 8 of Standard Set) Shows Pronounced Gas Porosity — Especially in Lower Casting — and Blowholes in Linear Formation. Not Acceptable

by hot shortness, and are more nearly linear, or straight, and of more constant width when originating from residual stresses in solid metal.

Shrinkage. Shrinkage cavities are represented by dendritic or filamentary dark regions of irregular dimensions and indistinct outline, and are caused by an insufficient supply of molten metal to feed the particular section.

Cold Shuts are represented by darkened areas of variable length and smooth outline which tend to be elongated and thin. They occur where the streams of molten metal have come together and have failed to weld together, so that the contact surfaces are oxidized. Cold shuts may generally be detected by visual examination.

Misruns appear as darkened areas of variable dimensions and smooth outlines where the molten metal has failed to fill the section. Misruns can always be seen by visual examination.

Gas Porosity is generally found in aluminum alloy castings and is due to the presence of dissolved hydrogen in the molten metal. It appears as a well distributed peppering of round or irregular dark spots which tend to be elongated or curved in coarse grained castings. The porosity is distributed throughout the casting, the size of the holes varying with the gas content of the metal and the rate of solidification of the section.

Microshrinkage commonly appears in magnesium alloy castings, and occasionally in castings of other alloys, as dark feathery streaks, or as massive areas of fairly definite outline.

Blowholes or gasholes usually appear as well defined spherical or rounded darkened areas. They are caused by trapped air, mold or core gases, or water vapor and are random in occurrence but tend to distribute on the cope side of a casting.

Dross Inclusions. Dross or oxide inclusions appear as small darkened regions of irregular or indistinct outline, varying in intensity. These tend to be random in occurrence but may become localized in the cope side of a casting.

Sand Inclusions appear as gray spots of uneven granular texture with indistinct outline. They are random in occurrence but tend to concentrate near the drag side of a casting.

Segregation of metallic inclusions (whether or not these properly constitute alloying elements) appear as well defined white spots or as mottled areas, regular or irregular in shape.

Mottling appears as a pattern of alternate light and dark areas which tend to the size and shape of the macroscopic grains and is due to the difference in chemical composition between the grain and grain boundary material; most frequently found in aluminum alloy castings.

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