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DIVISION OF PHYSICAL METALLURGY
STEEL CASTINGS SECTION

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INTERNAL AND EXTERNAL HOT TEARS--THEIR DISSIMILARITY AS TO APPEARANCE, ORIGIN, AND MEANS OF ELIMINATION

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ABSTRACT

The defect in steel castings commonly known as an internal hot tear is a crack within the casting resulting from shrinkage and inadequate feeding. The external hot tear, caused by restrained contraction, is visible on the surface. Since these two defects arise from different conditions and are remedied by unlike methods it is important that they be properly identified when observed on radiographs so that they can be eliminated. The internal shrinkage tear and the external hot tear have individual characteristics which make their identification possible. Typical examples of both types are illustrated and discussed.

Authorization

1. This research project in steel castings was authorized by the Bureau of Ships letter 28/A2-11 of 22 June 1943.

Statement of Problem

2. Briggs and Gezelius (1, 2) and Briggs (3, 4) have pioneered the study of hot tears in the United States, particularly the effect of free and hindered contraction on carbon and alloy steels. It is felt, however, that they have not sufficiently explained the difference between external and internal hot tears, both as to their appearance and causes. External hot tears, when viewed on radiographs have often been called internal hot tears, usually because they were too small to be readily seen on the casting surface. Radiographs of miscellaneous castings made at the Naval Research Laboratory indicated that internal and external hot tears have characteristics which make it possible to identify them. Furthermore, the internal and external tears are caused and eliminated by means so unlike as to make it necessary that they be considered as separate defects. The purpose of this work is to supplement that of Briggs and Gezelius with a more detailed description of the internal and external hot tear that emphasizes the appearance of each in radiographs.

General Considerations

3. The term "internal hot tear" is applied to a crack-like defect that commonly occurs in steel castings. This defect is not visible to the eye and thus is distinguished from the "external hot tear" which appears on the casting surface and extends toward the interior.

4. External hot tears have a rough irregular appearance and form in castings soon after the metal has been poured. They are caused by interference with the normal contraction of the castings. This interference may be the result of one of two things, mold resistance or resistance due to the design of the casting where one part is restrained from contracting by other parts of the same casting.

5. In addition to the presence of stresses which restrain contraction, one other condition must exist before an external hot tear can occur: a region must be present in the casting which is lower in strength than the rest of the casting. This weak area is usually the hottest part of the casting and is the point at which elongation or failure must occur. Hot areas are found at the gates or risers of the casting, at internal corners, or in heavy sections which are joined to lighter sections. When no hot zones are present the strains are distributed evenly throughout the casting; and, if it must deform to accomodate the stresses which resist its contraction, this deformation, which is extremely small, will occur uniformly throughout the casting. If a hot weak area is present, the deformation for the entire casting will occur at this localized area and may result in a hot tear.

6. Briggs (5) and Hall (6) have cast steel into tensile bar molds contained in tensile machines and have broken the bars after solidification and cooling to the desired temperature. They found that at temperatures just below the solidification temperature, a plain 0.25 percent carbon steel has practically no strength and ductility. As the casting cools, however, the strength builds up very rapidly. The ductility of the steel as measured by elongation remains below 1.0 percent until a temperature of 2372°F (1300°C) is reached and then, as the temperature continues to drop, the ductility increases very rapidly. Thus it appears that a steel containing about 0.25 percent carbon will tear at temperatures near the solidification temperature when both strength and ductility are low, and certainly will tear above 2372°F (1300°C) before the steel develops ductility.

Description of Typical Examples of Hot Tears

7. Some external hot tears, easily recognized as such, are shown in Figures 1 through 4. These tears are a result of the two conditions prerequisite to tearing, a hot weak zone and a stress which prevents normal contraction. Figure 1 shows a cast-steel magnesium melting pot gated through a blind riser placed at its bulge. Circumferential contraction of the pot was restrained by an extremely hard core, which caused the tear to occur at the hot zone beneath the riser. Until this mold was filled to the level of the riser, all of the metal entering the mold flowed over the area where the tear occurred, preheating it and making this zone hotter than the remainder of the mold. This casting was made sound by using a hollow core made of green sand so that it was easily broken by the contraction stresses.

8. Figure 2 shows a cast steel torpedo tail cone containing external hot tears. The heavy ribs on the outside of the cone cause hot zones to develop, and again the stresses are caused by contraction of the casting against the core. The tears in the tail cone can be eliminated either by using a weak core, or by chilling the ribs so that their solidification rate is accelerated and the metal strength at the ribs is then comparable to that of the thin walls adjacent to them.

9. The photograph of Figure 3 shows a section of a four-bladed propeller with an external hot tear at the junction of the blade and hub. The hot zone is the internal corner at the junction. The curvature of the blade prevents it from contracting toward the hub and hence tearing occurs.

10. Figure 4 is a photograph of a typical external hot tear found in flat sections.

11. The mechanism of external hot tear formation is illustrated in Figure 5 for a section through the tail cone shown in Figure 2.

In A of Figure 5, the tail cone is shown soon after pouring. The skin thickness of the solidified metal on the core surface of the mold is uniform, because, as Briggs and Gezelius have pointed out, the thickness of the solidified skin is the same regardless of section size. While this conclusion does not hold for large sections, it is essentially correct for the section sizes discussed herein. Thus, although the rib section is about $2\frac{1}{2}$ inches in thickness and the section adjoining it is only about 3/4 inches in thickness, the initial solidification rate is the same. The heat extracted by the core is almost entirely heat of fusion. Illustration B represents the tail cone when the sections adjoining the ribs have just completed solidification. However, the rib sections, since they are of greater mass, are still partially liquid. After this stage in the cooling, the hot zone is beginning to form; further heat extracted from the thin section by the core serves entirely to cool this section, while heat extracted from the rib section is still heat of fusion evolved in further solidification. Since the surfaces beneath the ribs are hotter than the remainder of the casting, they are also weaker and become points favorable for the occurrence of hot tears.

12. In the case of the magnesium pot, although its cross section was uniform, the tear occurred at the last part to solidify. All of the metal flowed over the sand at the zone where tearing occurred thus preheating the sand so that it was less capable of removing heat from the metal which finally came to rest in the region of the tear. The result was that, after the remainder of the casting had solidified and was cooling, the metal in the mold beneath the riser was still giving off heat of fusion to complete its solidification.

13. These external hot tears of Figures 1 through 4 are all severe and easily detected on the castings. More frequently, however, they are slight and are obscured by the oxide on the casting surface. Frequently they are not discovered until the casting has been radiographed; but, after a thorough sandblasting and careful examination of the area containing the tears, they can usually be seen directly.

14. Figures 6 through 9 are photographs of radiographs of external hot tears. These radiographs were reduced in reproduction to half their original size. External hot tears are parallel wavy cracks running in a direction perpendicular to the axis of stress. They do not have branches leading from them, but may exist as individual short parallel cracks in roughly an echelon formation.

15. Internal hot tears are found in imperfectly fed castings. They differ in appearance from the external tears in that they have no particular orientation, may run in all directions, and usually have small cracks branching off from the larger cracks. Since the internal crack is invariably near a shrinkage cavity or a low density area it is apparent that they are associated with shrinkage. To determine the effect of inadequate risers on the internal hot tear, a series of plates 8 inches long, 6 inches wide and $1\frac{1}{2}$ inches thick was

cast and fed by increasingly larger risers. Figure 10 shows a radiograph of the first plate of the series. This plate had no riser attached to it and the only feeding which could take place was the small amount from the gate. Plates 11, 12, 13 and 14 show radiographs of the other cast plates in the series which had risers attached to one side. It is apparent that the severity of the cracks is reduced as the size of the risers is increased, and when the casting is sufficiently risered, as in Figure 14, the defect disappears completely. This leads to the conclusion that the internal hot tear is in reality a form of shrinkage and can be eliminated by adequate feeding. Figure 15 is a reproduction of a radiograph showing the occurrence of internal hot tears in the midst of more conventional shrinkage. This occurrence is common. These radiographs illustrate the characteristics which identify an internal hot tear: lack of orientation, "branching" or "lightning-like" appearance, and proximity to low density areas.

16. Figures 16 and 17 show radiographs of internal tears in vertically cast plates. These castings were deliberately underrisered, each having only a small riser on one corner. The cracks in these photographs show a pronounced "branching" effect.

17. Radiography has been found to be the only reliable means of detecting internal tears, although it is probable that very severe internal tears, which extend to within a short distance of the casting surface, can be found by magnetic powder testing methods if a very high current is used. The magnetic powder test is ideally suited for detecting external tears. Very minute external tears, which may not be found by radiography, are disclosed by the magnetic powder test.

18. It is important that the internal and external hot tears be identified correctly and considered as different defects because the methods of preventing them are completely different. In fact, the remedy for the internal or shrinkage tear may make conditions favorable for the external hot tear to form.

19. Two castings were made with dimensions as shown in Figure 18. One casting was made as shown in Figure 19 with open risers on each flange. It is obvious that there must be shrinkage in the center portion of this casting because it is impossible to feed the 1-1/2 inch center section through the 1 inch thick members which join the center plate to the flanges. Figure 20 is a reproduction of the radiograph of this section showing how part of the shrinkage occurred in the form of cracks or internal hot tears. Risers attached to the center plate section should eliminate the internal tear. Such a casting was made as shown in Figure 21 with risers on each side of the plate and chills on the back of the flanges. The risers were large enough to make the casting sound; but, when the center plate of this casting was X-rayed, it was found that, although the internal tears had been eliminated, external tears were present, as can be seen in Figure 22. The risers, because of their mass and the fact that the metal was gated into them, intensified the hot zone at the center of the casting, and,

with contraction restrained by the molding sand between the flanges, external hot tears resulted. The correct way to make this casting sound is to use the risering method shown in Figure 19 but to chill the center plate section so that it freezes before the 1 inch members, thus allowing solidification to begin at the center and proceed progressively in each direction toward the risers. Correctly designed chills, properly used in certain applications such as the casting described above, will eliminate both internal and external hot tears. The shrinkage defect is eliminated due to the accelerated rate of solidification of the metal adjacent to the chills; the chill at the same time strengthens the metal in this area by rapid cooling so that it can resist the stresses which would cause external tears. If the chills are improperly used they will serve only to move the defects elsewhere in the casting.

20. Figure 23 shows a radiograph of a cast steel plate containing internal tears or shrinkage cracks, and Figure 25 shows sections of this plate cut through the defect. Figure 24 shows a radiograph of a similar plate containing external tears, while Figure 26 is a photograph of sections cut from this plate perpendicular to the tears. The specimens of Figures 25 and 26 were etched with a 50 percent hydrochloric acid solution to show the defects in greater detail. Although the specimens of Figure 26 appeared completely free of shrinkage, the etching treatment disclosed centerline weakness in some of the specimens. It will be noticed that the external tears are widest at the surface and diminish in width as they extend inward toward the casting interior, while the opposite relation holds true for internal tears.

21. While the authors are convinced that internal tears are closely allied with shrinkage and that all internal tears can be eliminated by adequate risers, they can advance no explanation of the mechanics of internal tear formation, although several theories are being considered and it is planned to conduct experiments to test their validity.

Summary and Conclusions

22. The internal hot tear which can more accurately be called a shrinkage crack, and the external hot tear, which is a tear in the true meaning of the word, must be correctly identified so that the proper measures can be employed to eliminate them.

23. External hot tears are formed when the contraction of the casting, during cooling, is restrained by stresses arising either from the mold or from the casting design. Internal hot tears are the result of inadequate feeding.

24. External hot tears are eliminated either by the judicious application of chills or brackets which strengthen the metal, making it capable of resisting the tearing stresses, or by using weak sand or relieving cavities which enable the mold to collapse, thereby relieving the stresses. Internal hot tears are eliminated by any of the means which are used to prevent shrinkage.

25. Severe external hot tears are easily seen on the surface of the casting. Slight tears may be overlooked in a cursory inspection but will be discovered when the casting is sandblasted, radiographed, or subjected to a magnetic powder test. The only reliable means of detecting internal tears is by radiography.

26. On a radiograph, the internal hot tear will show branches emanating from the main crack, while the external tear does not. External tears are roughly parallel to each other and do not cross, while the internal tears have no particular orientation.

27. An external hot tear will occur in a perfectly fed casting while an internal hot tear will not. Internal tears are found in the presence of shrinkage cavities or spongy, low density metal.

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2. Briggs, C. W. and Gezelius, R. A., "Studies on Solidification and Contraction in Steel Castings," II Trans. American Foundryman's Association, Vol. 42, pp. 449-476 (1934).

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4. Briggs, C. W., "Hot Tears in Steel Castings," Trans. American Foundryman's Association, Vol. 51, pp. 57-85 (1943).

5. Briggs, C. W., NRL Report M-1479 (1938).

6. Hall, H. F. "British Iron and Steel Institute, Special Reports 15 and 23.

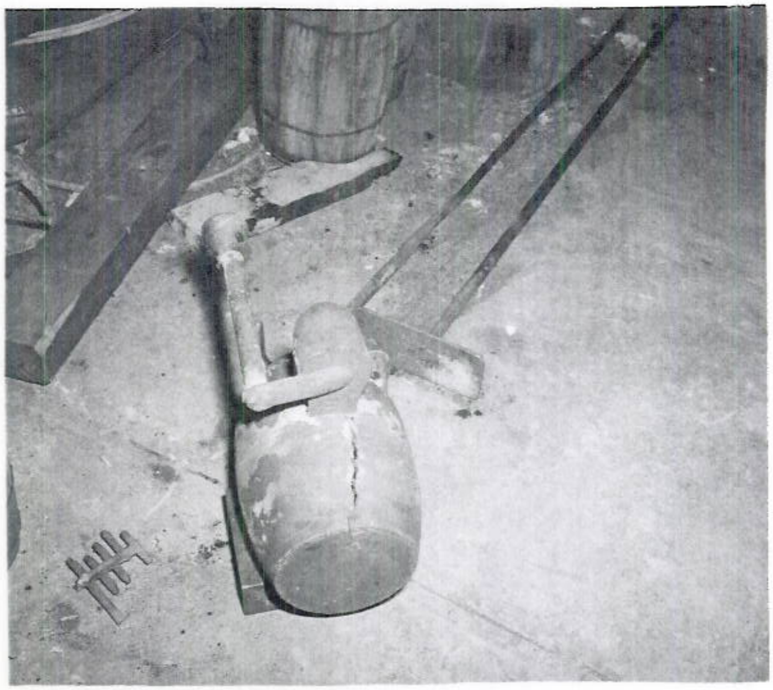


FIG. 1 EXTERNAL HOT TEAR IN CAST STEEL POT.

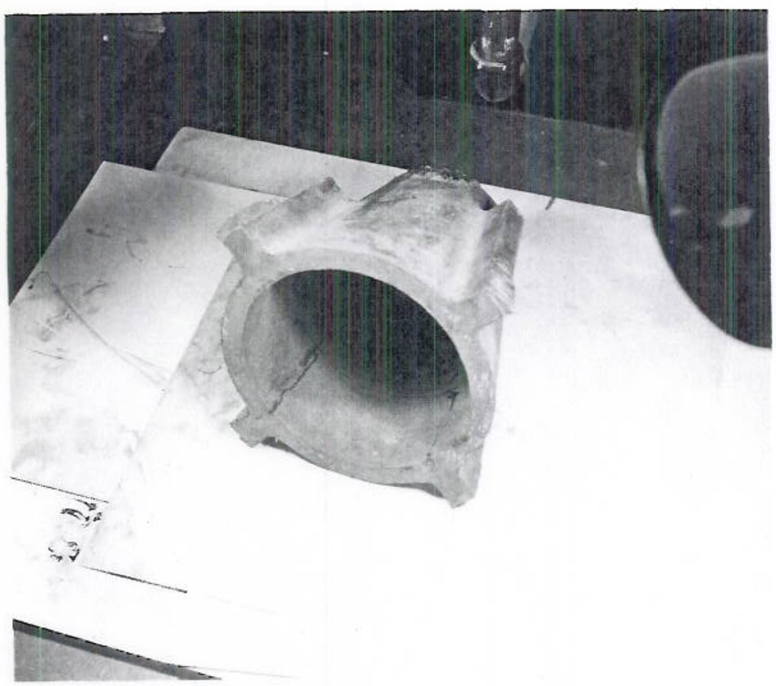


FIG. 2 EXTERNAL HOT TEAR IN TORPEDO TAIL CONE.

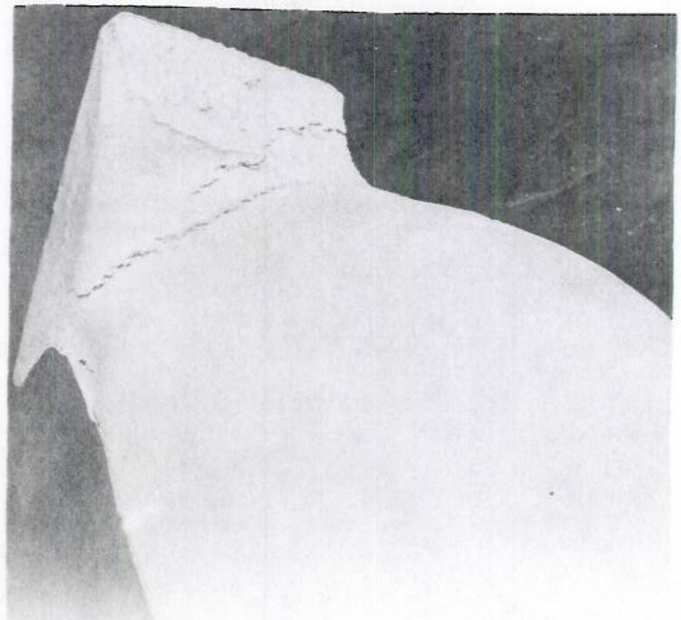


FIG. 3 EXTERNAL HOT TEAR AT JUNCTION OF PROPELLOR BLADE AND HUB.

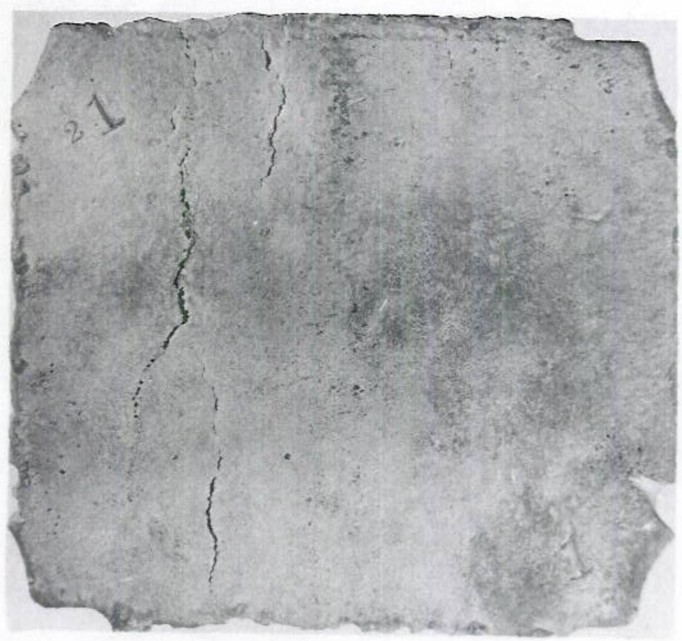
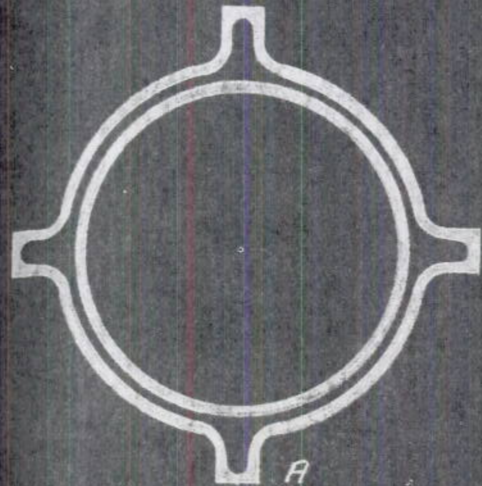
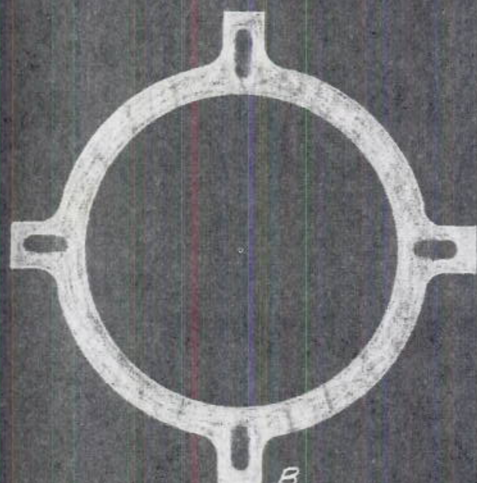


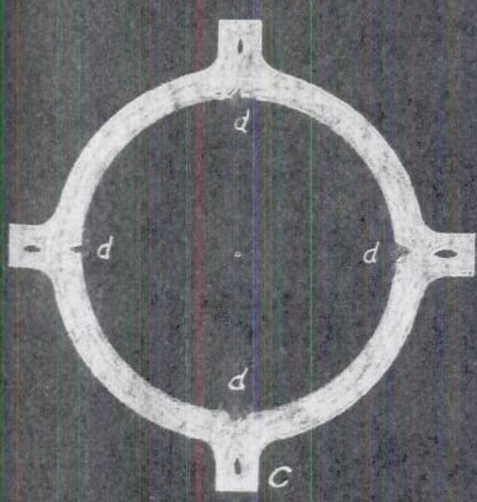
FIG. 4 TYPICAL EXTERNAL HOT TEAR FOUND IN FLAT SECTIONS.



UNIFORM SKIN OF METAL ON ALL MOLD SURFACES SOON AFTER POURING. NO HOT ZONE PRESENT.



THIN WALL SECTIONS HAVE JUST SOLIDIFIED, WHILE THE RIB SECTIONS ARE STILL PARTIALLY MOLTEN. NO HOT ZONE IS PRESENT AND HENCE NO HOT TEARS. ALL HEAT EXTRACTED BY THE MOLD SO FAR HAS BEEN HEAT OF FUSION.



HEAT CONTINUES TO BE REMOVED FROM METAL, AND THE RIBS ARE NOW ALMOST SOLIDIFIED. HEAT LOST BY THIN WALL IS SERVING ENTIRELY TO LOWER WALL TEMPERATURE. HEAT EXTRACTED FROM RIB SECTION IS HEAT OF FUSION LOST IN FURTHER SOLIDIFICATION OF RIBS WITHOUT LOWERING OF TEMPERATURE. HOT ZONES ARE THUS PRESENT AT RIBS AND TEARING HAS BEGUN AT "d"

FIG. 3 MECHANISM OF EXTERNAL TEAR FORMATION

PLATE 3

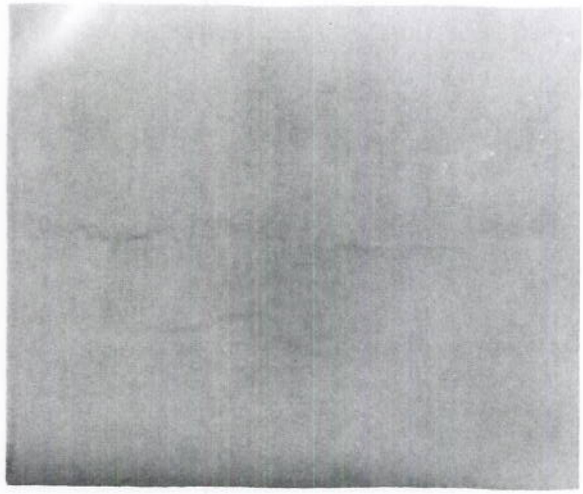


FIG. 6 RADIOGRAPH OF EXTERNAL HOT TEARS.

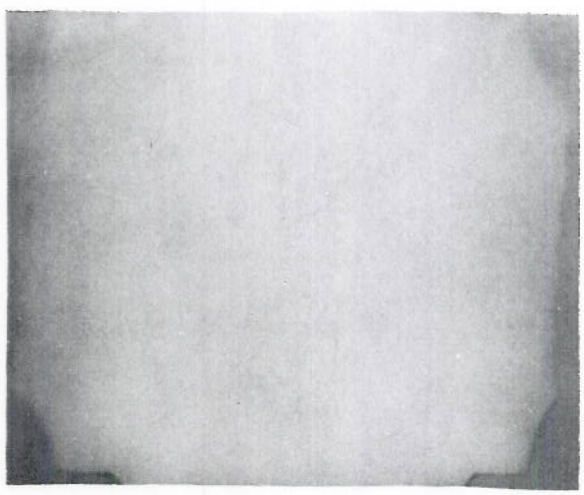


FIG. 7 RADIOGRAPH OF EXTERNAL HOT TEARS.

FIG. 8 RADIOGRAPH OF EXTERNAL HOT TEARS.

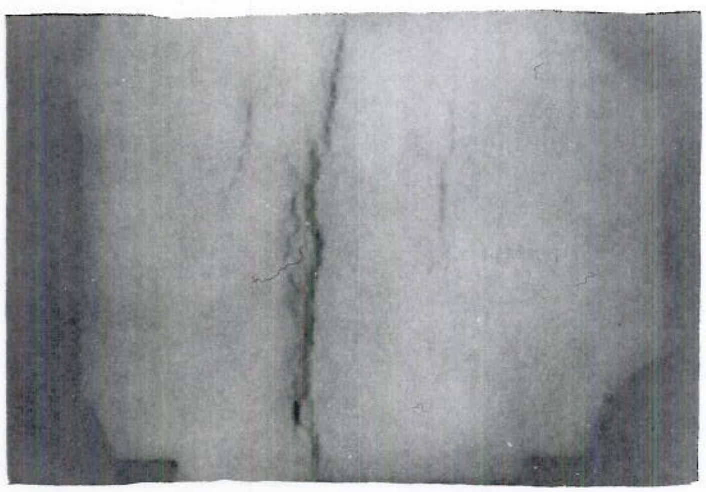


FIG. 9 RADIOGRAPH OF EXTERNAL HOT TEARS.

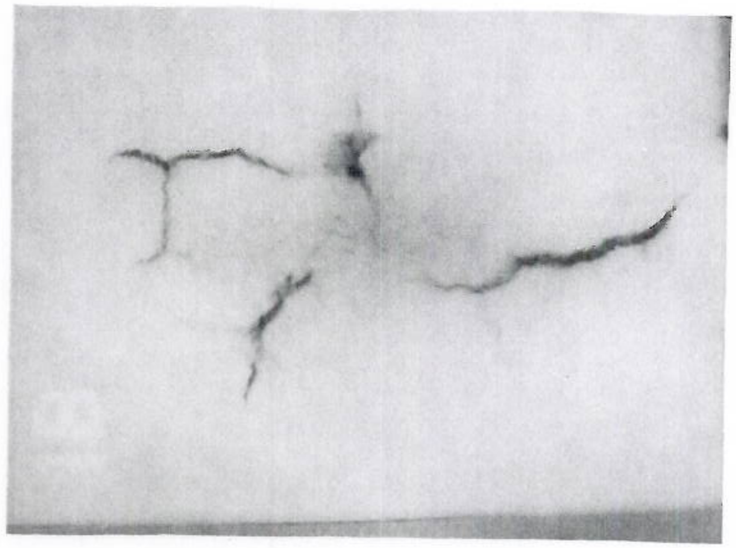


FIG. 10 RADIOGRAPH OF 6x8x$1\frac{1}{2}$ INCH PLATE CAST WITHOUT RISERS.

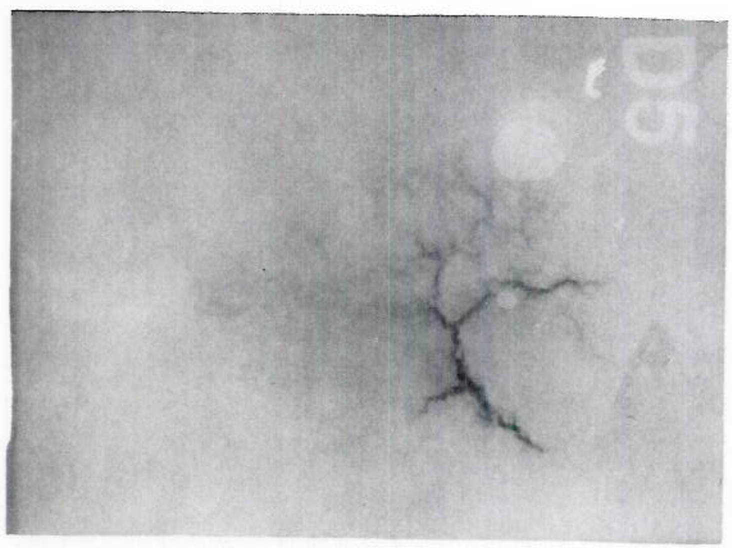


FIG. 11 RADIOGRAPH OF 6x8x$1\frac{1}{2}$ INCH PLATE FED BY BLIND RISER $2^3/_8$ INCHES DIAM. 3 INCHES HIGH.

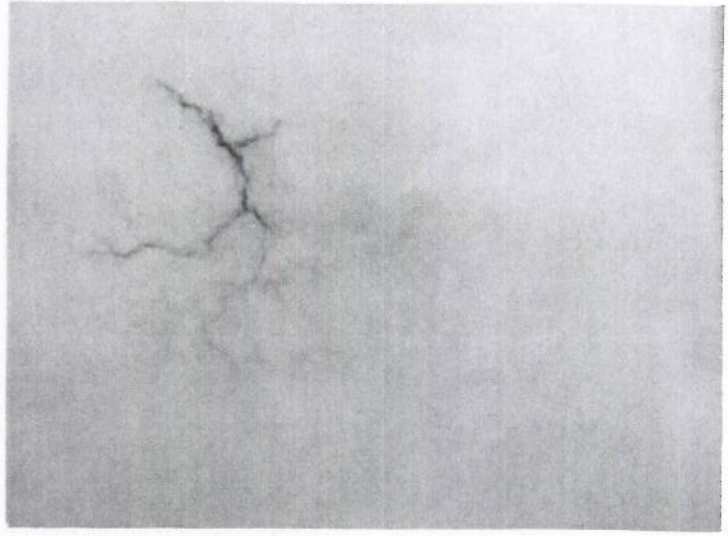


FIG. 13 RADIOGRAPH OF 6x8x1½ INCH PLATE FED BY BLIND RISER 3½ INCHES DIAM. 4 INCHES HIGH.

FIG. 12 RADIOGRAPH OF 6x8x1½ INCH PLATE FED BY BLIND RISER 3¼ INCHES DIAM. 3½ INCHES HIGH.

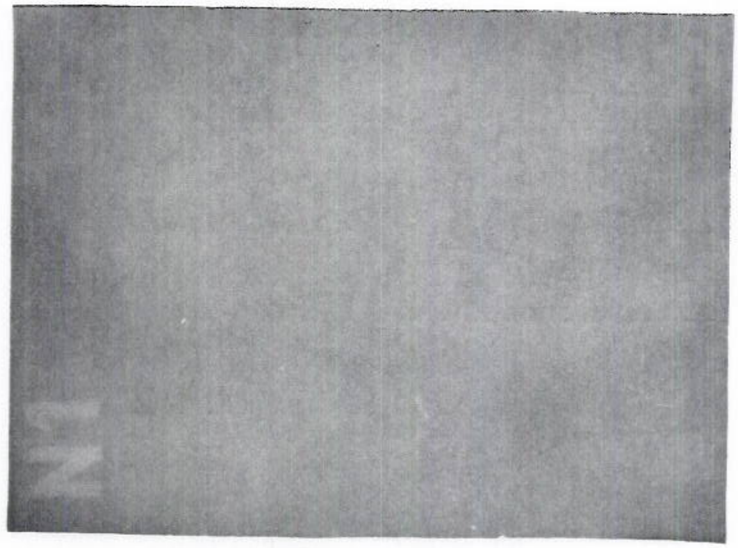


FIG. 14 RADIOGRAPH OF 6x8x1½ INCH PLATE FED BY BLIND RISER 4 INCHES DIAM. 5 INCHES HIGH.

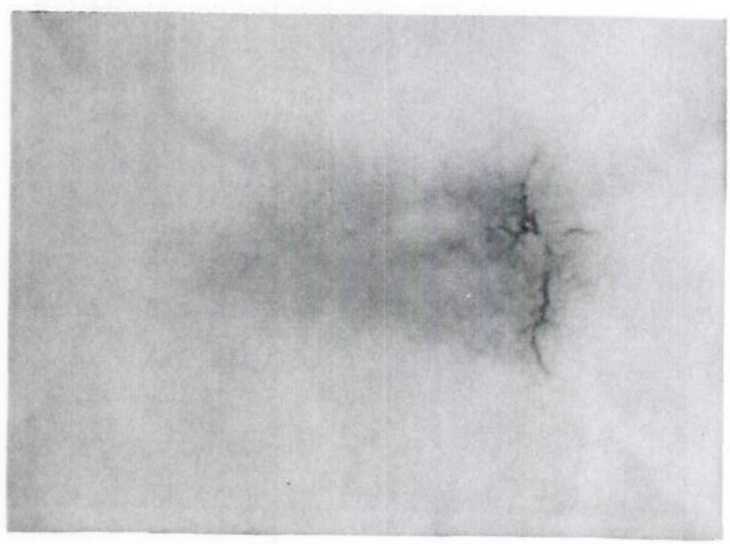


FIG. 15 RADIOGRAPH OF INTERNAL HOT TEARS AND CONVENTIONAL SHRINKAGE.

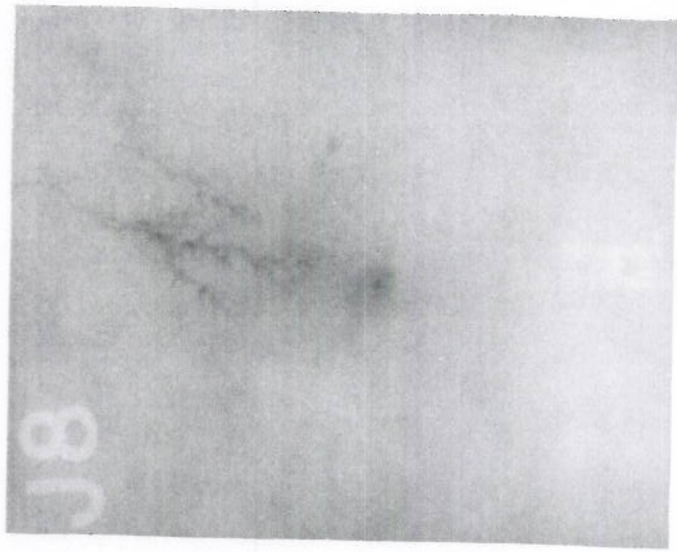


FIG. 16 RADIOGRAPH OF INTERNAL HOT TEARS IN VERTICAL SECTION.

FIG. 17 RADIOGRAPH OF INTERNAL HOT TEARS IN VERTICAL SECTION.

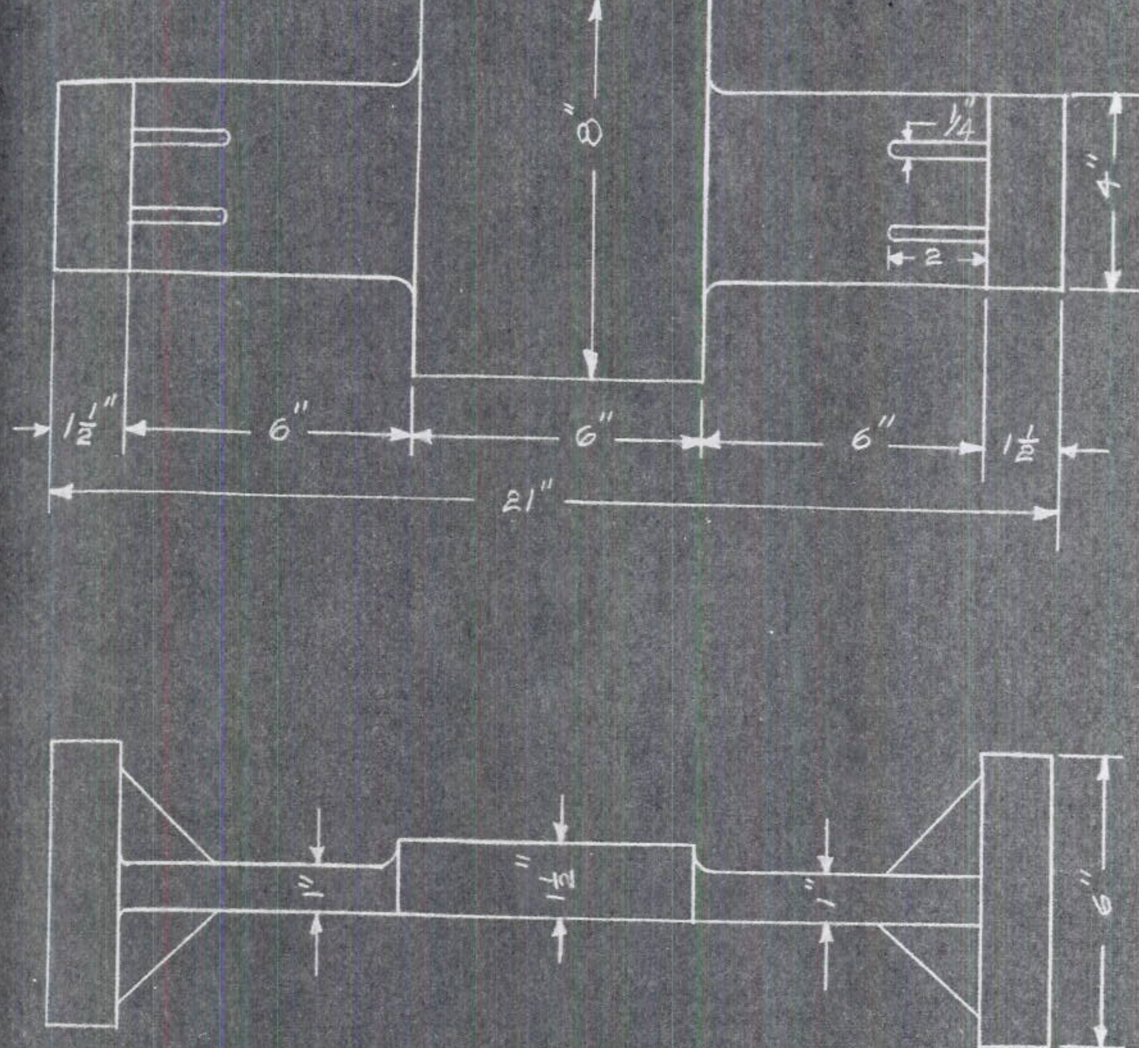


FIG. 18 HOT TEAR TEST SPECIMEN

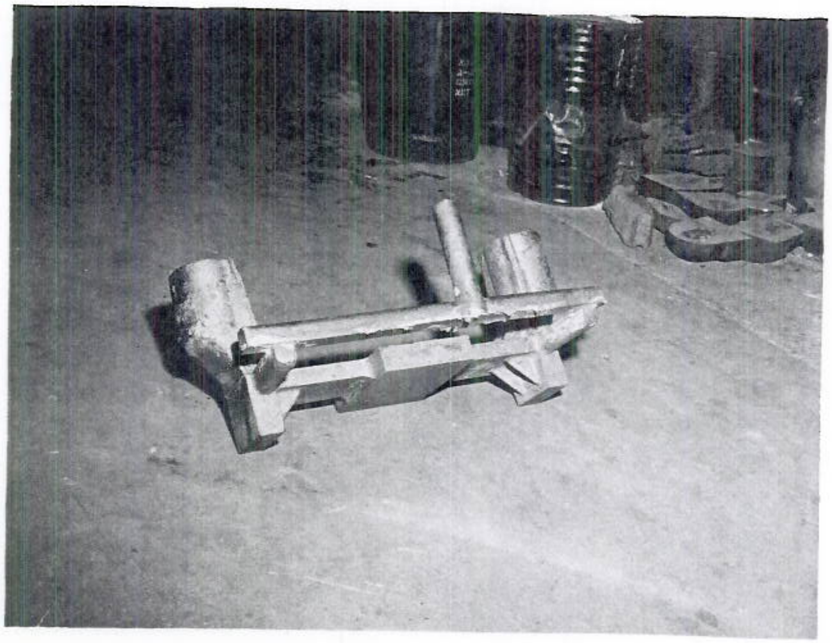


FIG. 19 CASTING OF FIG. 18 RISERED TO PRODUCE SHRINKAGE TEARS.

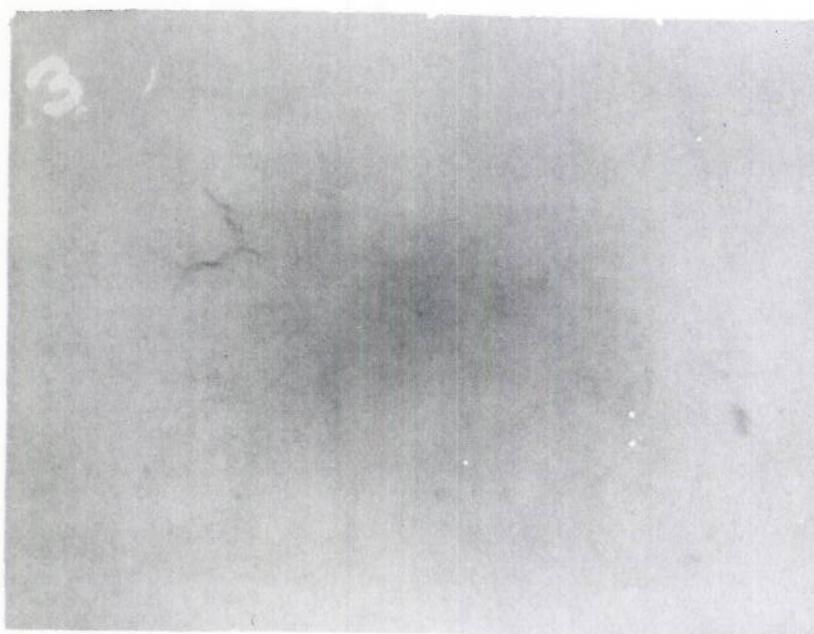


FIG. 20 RADIOGRAPH OF CENTER SECTION OF CASTING SHOWN IN FIG. 19.

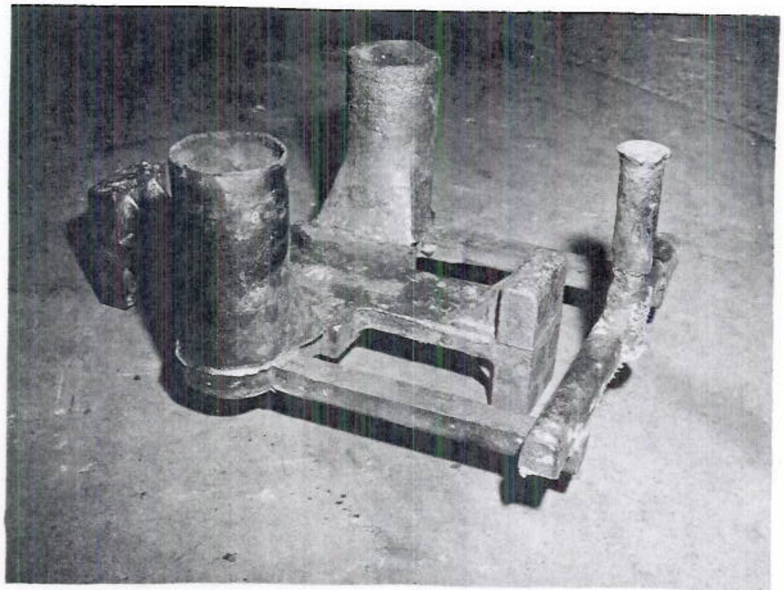


FIG. 21 CASTING OF FIG. 18 RISERED SO THAT EXTERNAL HOT TEARS WILL FORM.

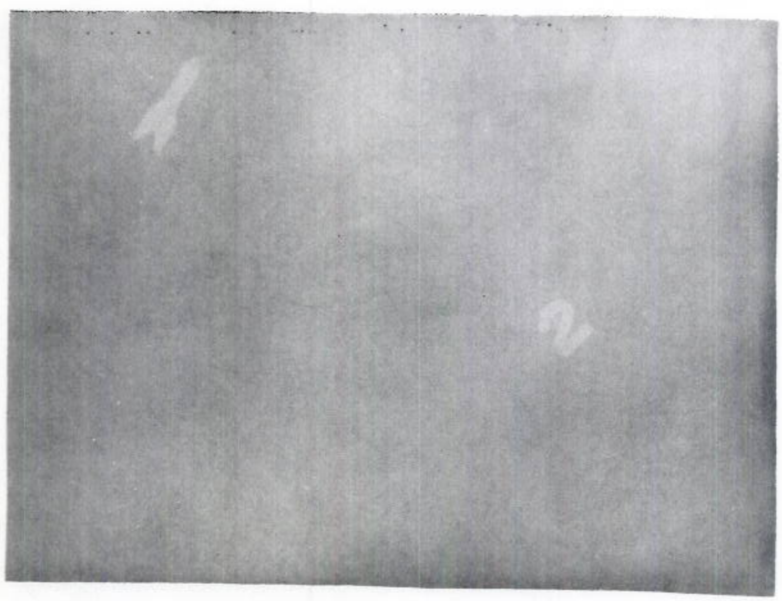


FIG. 22 RADIOGRAPH OF CENTER SECTION OF CASTING SHOWN IN FIG. 21.

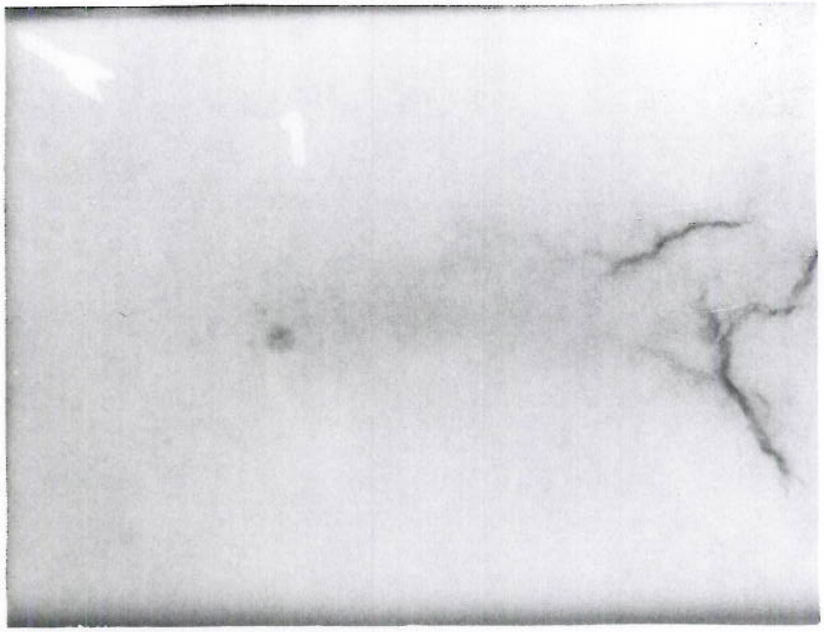


FIG. 23   X-RAY OF INTERNAL HOT TEARS CAUSED BY INADEQUATE RISERS.

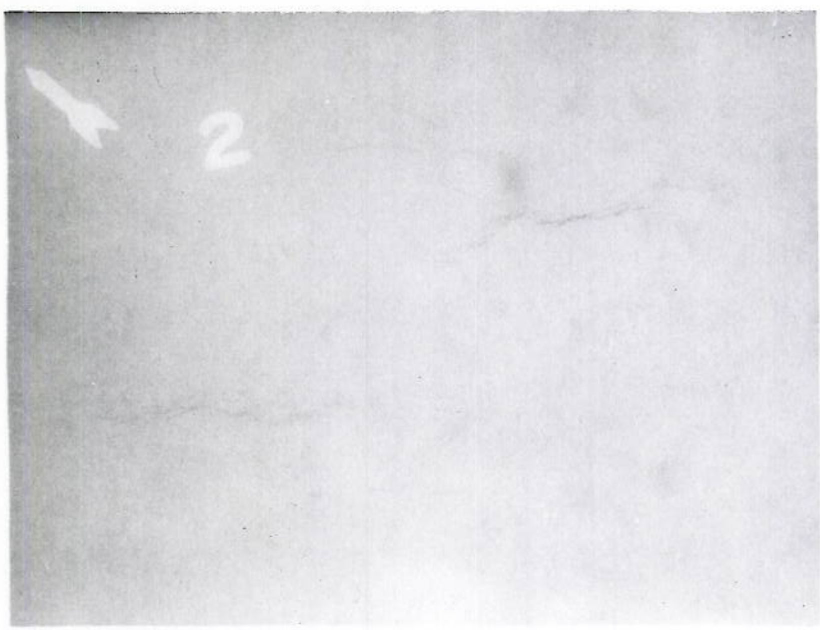


FIG. 24   X-RAY OF EXTERNAL HOT TEAR CAUSED BY MOLD RESISTANCE.

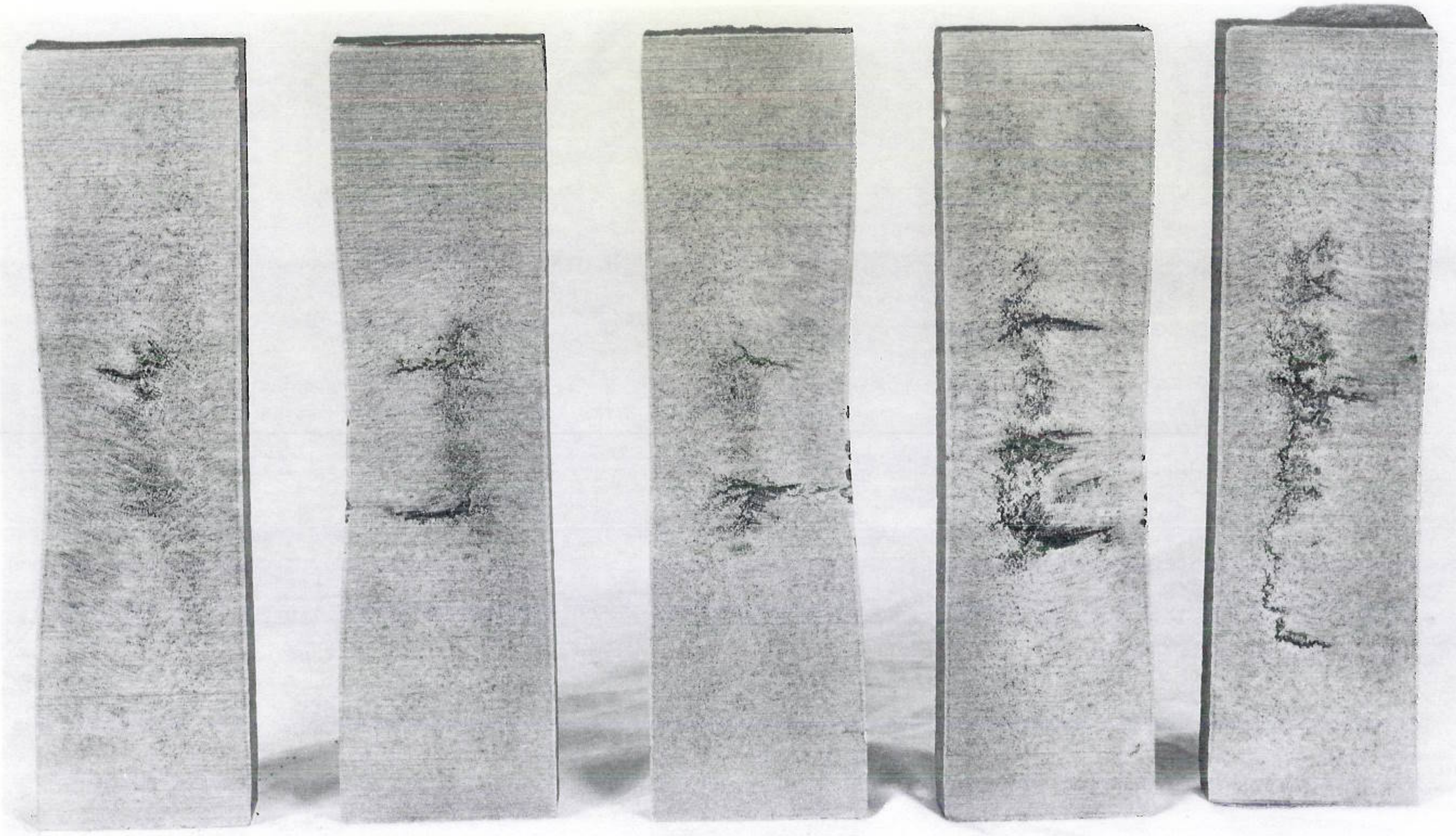


FIG. 25 SECTIONS THROUGH INTERNAL HOT TEARS OF FIG. 23.