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METALLOGRAPHIC EXAMINATION AND HEAT TREATMENT OF CASTINGS FOR FLEXIBLE RADIOGRAPHY CABLES

by

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SUMMARY OF RESULTS

Metallurgical examination was made on reject AISI-420 stainless steel castings used in the manufacture of couplings for radiographic equipment. Service failures were also examined and were of the tensile type with evidence of bending prior to rupture.

Castings rejected by the manufacturer for dimensional errors and for failure during crimping or tensile testing were also examined.

Recommendations were made concerning design changes to increase thickness stiffness and quality of the eye casting.

Laboratory heat treatments and examination of defective castings confirmed that a hardness of R_c21-23 was optimum for drilling, crimping and service. A controlled cooling heat treatment procedure was established, and a trial production run of 200 castings was heat treated for Atomic Energy of Canada Limited.

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INTRODUCTION

On October 12, 1966, ten reject male and ten reject female stainless steel castings were received from Mr. J. McLellan, Atomic Energy of Canada (file ref: 831-116 66-10-988), with the request that a heat treating procedure be determined which would ensure a final hardness of Rockwell C 21 to 23.

The samples were in the as-cast, air hardened condition and were purchased as AISI-420 stainless steel although check analysis for carbon showed variation in carbon between 0.09% and 0.32% with about 70% of the castings also conforming to the 0.15% maximum carbon requirement for AISI-410 stainless steel.

The hardness of the as-received castings was approximately R_c50.

Subsequent tests were made in which the as-received castings were tempered at temperatures as high as 1350°F and one test in which the castings were re-austenitized, oil-quenched and tempered at 1300°F; however, neither of these treatments reduced the hardness to R_c21.

The required hardness was attained by austenitizing at 1550°F for five minutes, with the atmosphere set for 0.15% carbon, followed by controlled furnace cooling at 40°F per hour to 850°F and air cooling to room temperature. The hardness obtained was in the range R_c 21 to 23. Subsequent crimping tests showed that these annealed castings successfully withstood a single crimping operation but that difficulty was experienced when a double crimping operating was used. (Failure during double crimping was later ascribed to non-uniform wall thickness caused when the casting base was drilled to accommodate the cable and was rectified by ensuring that drill holes were centred.)

In addition to the routine heat treatment, which was accomplished by annealing at 40°F per hour, several sets (Table 1) of reject castings that had failed either during manufacture, crimping at the plant or in service, were submitted for examination.

Nine random reject links were annealed and drilled for carbon analysis as shown in Table 2.

The hardness obtained by experimental heat treatment of reject female (links) is shown in Table 3.

TABLE 1

Castings (Links and Hooks)
Submitted for Metallurgical Examination

Number of Castings	Description	R_C Hardness of Castings	R_C Range
As-Received (3)	Female - In as-cast condition (air-hardened)		45/53
6 - Rejects	Female - Pulled loose at 100 lb test	22, 22, 22, 27, 30, 29	22/29
3 - Acceptable	Female - Withstood 175 lb test (links)	21, 21, 21	21
3 - Acceptable	Male - Withstood 175 lb test (hooks)	21, 21, 21	21
6 - Rejects	Female - Cracked while crimping	26, 23, 22, 22, 22, 98 R_B	26
3 - Rejects	Female - Unexplained lab fractures	26, 29, 31	26/31
2 - Service	Female - Service fractures (tension and bending)		

TABLE 2

Carbon Analyses (Per Cent)

Samples 1-9 inclusive	0.12; 0.09; 0.16; 0.14; 0.11; 0.32; 0.12; 0.18; 0.13

The range of carbon contents was 0.09% to 0.32% with 6 out of 9 having less than 0.15% carbon.

TABLE 3

R_c Hardness Obtained by Laboratory Heat Treatment

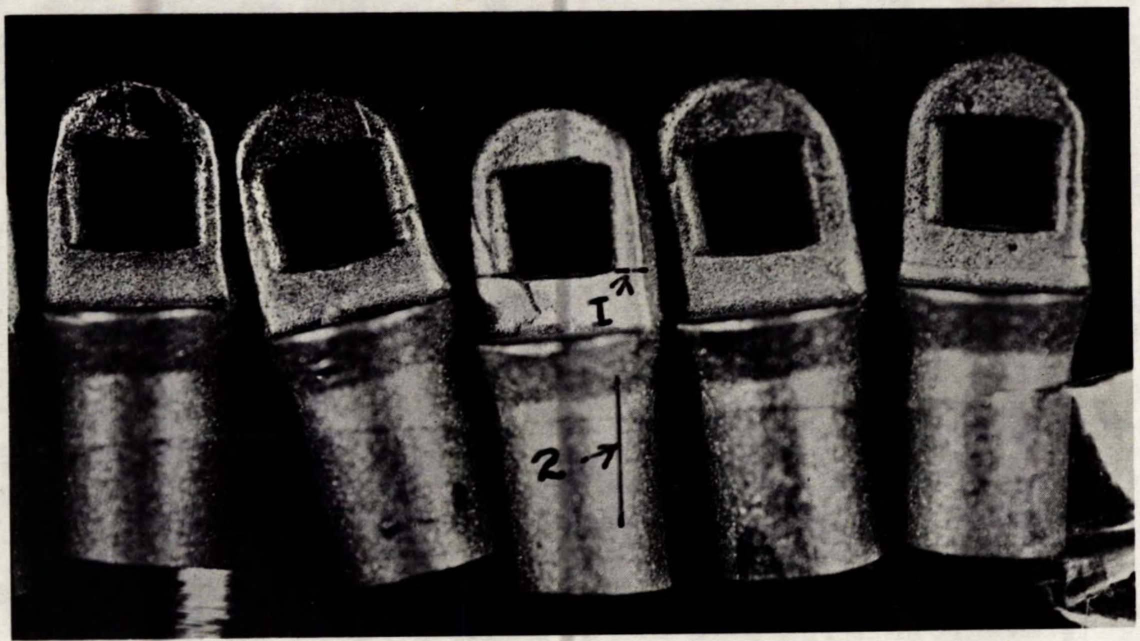
Heat Treatment	Hardness
As-Rec'd., Tempered 1100°F, Air Cooled	42-45 R_c
" " " 1100°F, Furnace Cooled	--
" " " 1200°F, Air Cooled	36-40 R_c
" " " 1200°F, Furnace Cooled	--
" " " 1350°F, Air Cooled	--
" " " 1350°F, Furnace Cooled	24-33 R_c
Heat 1700°F, Oil Quench., Temper 1 hr 1350°F, Air Cool.	30 R_c
" " " " " " ", Furnace Cool.	27-33 R_c
As-Rec'd., Heat to 1650°F*, cool at 100°F/hr to 1100°F, Air Cool.	25-44 R_c
As-Rec'd., Heat to 1550°F, hold 5 min, cool at 50°F/hr to 850°F, Air Cool.	23 R_c
As-Rec'd., Heat to 1550°F, hold 5 min, cool at 40°F/hr to 850°F, Air Cool.	21-22 R_c
As-Rec'd., Heat to 1450°F 1 hr, Air Cool.	24-30 R_c
As-Rec'd., Heat to 1450°F 1 hr, Furnace Cool.	34-38 R_c

*Excessive scale at 1650°F hence austenitizing temperature was reduced to 1550°F.

As-cast hardness = 45-53 R_c.

VISUAL EXAMINATION

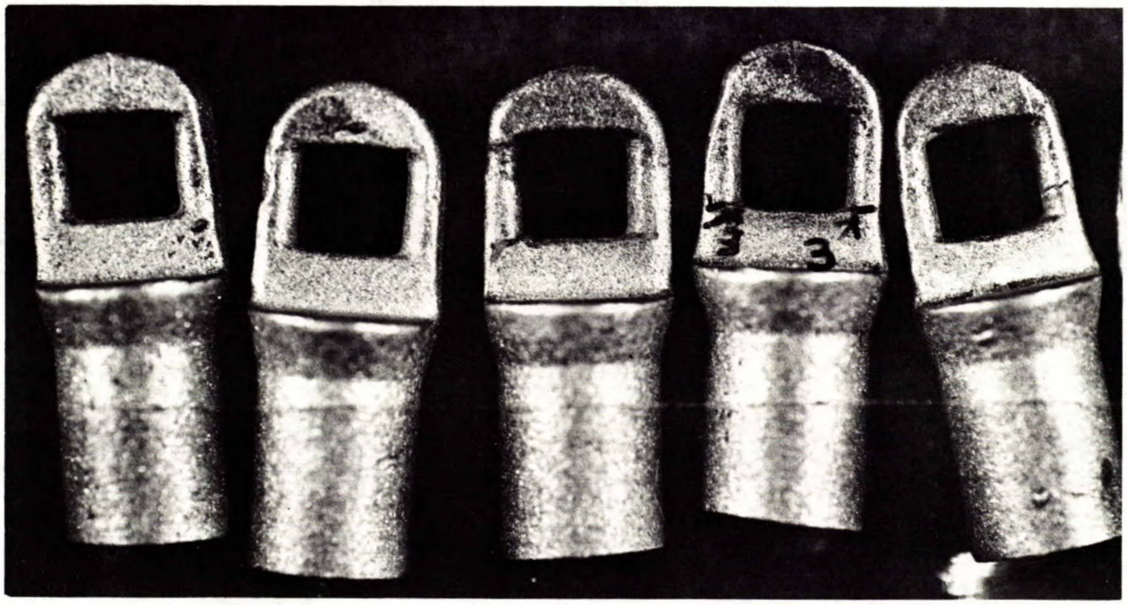
The appearance of female (link) as-cast reject couplings is illustrated in Figure 1. Other reject castings were submitted that had failed in test or in service. All fractured links showed cup-cone tensile fractures preceded by considerable bending on the critical section. The critical section is shown by the arrow 1 in Figure 1. Arrow 2 in Figure 1 illustrates the location where splits sometimes occurred. The splits were possibly caused by excessive crimping pressure or by thin walls due to misalignment of the drilled hole.



X5 approximately

Figure 1. As-Received, Cast AISI-420, Female Links.
The as-cast hardness, approximately R_c 50, is reduced to R_c 21 by furnace annealing at 40°F per hour. The base is then drilled to accept the cable and the cable is fastened by crimping. Arrows 1 mark the "critical section" where tensile rupture and bending occur. Arrow 2 marks the location where splitting can occur during crimping. These castings were rejected for dimensional errors and casting flaws.

Figure 2 shows the reverse surface to that of Figure 1 and illustrates the as-cast surface and the sharp corners, sometimes undercut and oxidized, where tensile failure occurs. These corners, arrows 3, sometimes show evidence of hot tears that reduce the metal thickness of the critical section. A design modification of the casting pattern is being made to achieve a stiffer and thicker loop section and to ensure a better radius at each corner of the hole.



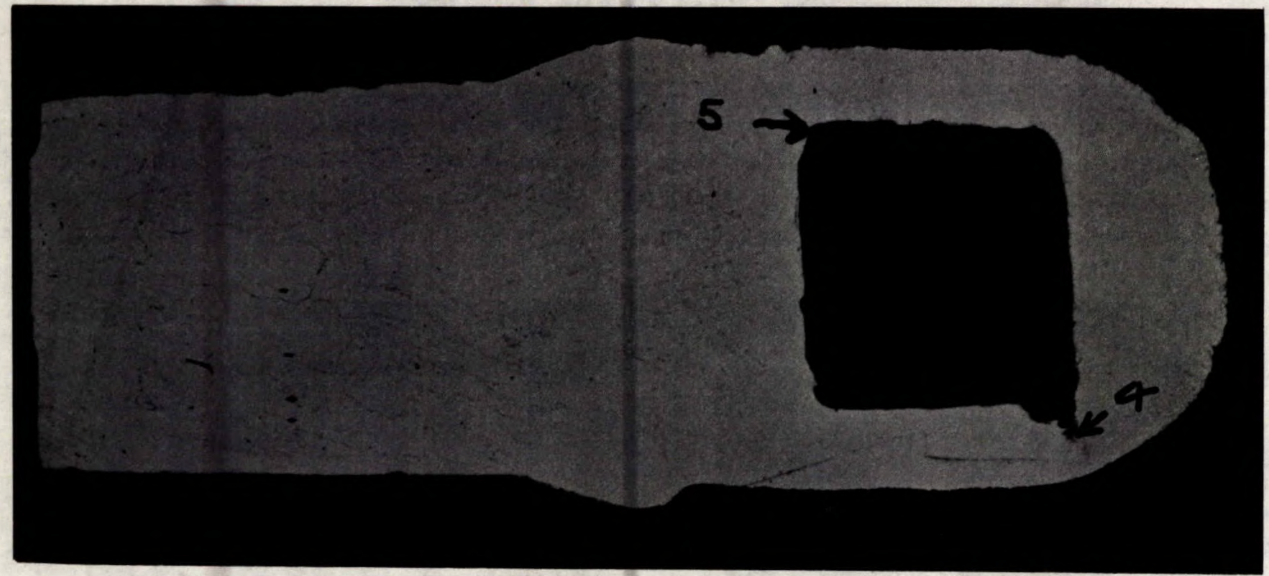
X5 approximately

Figure 2. Reverse Surface of Link Castings. This picture illustrates the square corners which sometimes contain hot tears. These defects when present in the corners (arrows 3) reduce the metal section and can act as stress-raisers.

METALLOGRAPHIC EXAMINATION

Two female links were chosen with surface defects. Figure 3 illustrates one of the castings having a hot tear in a second critical section where failure may occur when the link ruptures and opens.

Figure 4 illustrates the section, arrow 4 Figure 3, at higher magnification showing high temperature oxide which indicates that the crack formed and was open at high temperature, that is, during solidification of the casting.



X12 approximately

Figure 3. Metallographic Section Female Link, showing an oxidized hot tear, arrow 4, aligned with a critical section. The section has been reduced approximately 50% by the oxidized hot tear.

X100 as-polished

Figure 4. Hot Tear Marked by Arrow 4, Figure 3. Intergranular oxidation has occurred, indicating that the rupture has been exposed to air while at high temperature. This defect appears to be a "hot tear" casting defect.

DISCUSSION

Variation of carbon between 0.09% and 0.32% was observed. This carbon variation had less effect on final hardness in the full annealed (R_C 21) condition of heat treatment than in the quenched or tempered condition.

Dimensional variation, hot tears and sharp corners were observed in the critical section. Service failures appeared to have occurred in tension with evidence of bending. Design modifications were discussed having the object of stiffening the link, increasing the corner radius and increasing the section.

CONCLUSION

The heat treatment required to obtain R_C 21-22 for this batch of 200 castings was as follows:

Set 0.15% C atmosphere
Hold at 1550°F for 5 minutes
Cool at 40°F/hr to 850°F
Air cool 850°F to room temperature.

DEP:DAM:bb