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MINES BRANCH INVESTIGATION REPORT IR 64-65

EXAMINATION OF A FAILED CROSSARM BOLT

by

D. R. BELL

PHYSICAL METALLURGY DIVISION

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D.R. Bell*

SUMMARY OF RESULTS

Examination of the bolt showed no evidence of manufacturing defects. There was insufficient material for a room temperature tensile test. However, based on chemical composition and structure, it is estimated the bolt would have met the breaking load requirement of CSA C83-1950.

The charred black coating and staining of the bolt surface and the extreme reduction of area at the fracture indicated the occurrence of an elevated temperature at the time of fracture. Microstructural changes in the galvanized coating showed the high temperature was localized, being restricted to a length of approximately 7 in., centred at the service fracture. An elevated temperature tensile test and microstructural changes in the steel indicate the temperature in the area of the fracture probably was in the range of 650°C (1200°F) to 705°C (1300°F) with a most probable maximum at the fracture of 675°C (1250°F)

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Examination of Failed Crossarm Bolt

by

D.R. Bell
Ferrous Metals Section

INTRODUCTION

On 2 April, 1964, a broken 3/4 in. galvanized machine bolt was received from the New Brunswick Electric Power Commission via the Technical Information Services Division of the National Research Council. The letter from the Power Commission, file 3-352A, Line Design General, dated 12 March, 1964, inquired:

(a) If the bolt shows any defect or defects in manufacture.

(b) What were the probable conditions which would bring about such a break.

(c) What would be the probable temperature at the time of the break.

It was stated that the bolt had been installed in a power line pole holding a river crossing conductor at a tension of about 7000 lb. The conductor was insulated from the bolt with six suspension insulators. The bolt passed through the pole and the four-inch dimension of a 4 in. x 6 in. crossarm. Voltage of the conductor was 69 kV. The installation stood near the sea-coast where the conditions were usually damp. There were no severe conditions of aeolian vibration. The pole where the break occurred showed signs of burning.

VISUAL EXAMINATION

The major portion of the surface of the bolt was darkened, the colour ranging from a brownish-black stain to charred black adjacent to the fracture. The head, the threaded end, and the nut were not discoloured. The fracture was a typical tensile fracture exhibiting a high degree of ductility, the reduction in area at the fracture being approximately 90%.

CHEMICAL ANALYSIS

The results of chemical analysis of through-the-bolt drillings are shown in Table 1.

TABLE 1

Chemical Composition

Per Cent of Element

	Carbon	Manganese	Silicon	Sulphur	Phosphorus
Sample	0.13	0.72	0.01	0.12	0.009

METALLURGICAL EXAMINATION

Both the sulphur print and the deep etch of a transverse section of the shank of the bolt showed the typical macrostructure of rimmed steel.

The microstructure of the shank adjacent to the head of the bolt is typical of hot rolled mild steel, consisting of approximately equiaxed ferrite grains and patches of fine pearlite (Figure 1a). At 1/2 in. from the fracture, there is clear evidence of cold deformation of the ferrite (Figure 1b). At 1/4 in. from the fracture, there is severe cold work shown by the heavily deformed ferrite and also elongated, pearlite patches (Figure 1c). Immediately adjacent to the fracture, most of the ferrite has recrystallized, and the pearlite patches have been deformed to stringers of carbide particles (Figure 1d).

Examination of the galvanized coating revealed further evidence of elevated temperature. Figure 2a illustrates the galvanized microstructure on the shank approximately 3-1/2 in. from the fracture toward the threaded end. This reveals the original structure which shows the normal iron-zinc alloy phase layers, which are characteristic of this type of coating. There is no evidence of heating. At a point approximately 1 in. from the fracture the coating has been altered. There is little pure zinc, and the delta layer has grown at the expense of the columnar zeta layer (Figure 2b). Approximately 1/4 in. from the fracture the zeta layer has been completely replaced by the delta layer and, most significantly, the gamma layer has increased greatly (Figure 2c). These changes in microstructure are characteristic of post-galvanizing heating. The differences between the structures at 1/4 in. and 1 in. from the fracture are clear evidence that the section nearer the fracture was at a significantly higher temperature.

MECHANICAL TESTING

The normal discrepancy between mechanical properties of rim and core of a rimmed steel necessitates testing the full section. A tensile test of a 3/4 in. bolt requires a minimum length of 6 in. This restricted the number of tests to one. A room temperature tensile test appeared to be of limited value as the examination to this point did not suggest the material was defective and would probably conform to the specified requirements. Hence, it was decided to attempt an approximation of the actual failure. To this end, the sample was stressed to the service load of 7000 lb and this load was maintained constant within ± 150 lb throughout the test. The temperature was raised to approximately 370°C (700°F) at an average rate of 18 C°/min (32 F°/min). At this point, final adjustments were made to the furnace to ensure a proper temperature gradient on the sample. The temperature was then increased at the rate of 12 C°/min (21 F°/min) until fracture occurred. A thermocouple attached to the sample indicated a temperature of 675°C (1250°F) at the time of failure.

DISCUSSION

Specification CSA C83-1950, covering pole line hardware, incorporates no limits on chemical composition. It does require the material to have an ultimate tensile strength of 60,000 psi and the breaking load of 3/4 in. machine bolts must meet an 18,000 lb minimum requirement. It was not possible to carry out a room temperature tensile test on this bolt, but it is estimated from the chemical composition that it would probably have met the mechanical property requirements, although with little to spare. There was no evidence of metallurgical quality deficiency in terms of the specified requirements nor expected commercial practice for such an item. There was no evidence of manufacturing defects.

As to the third item of the inquiry, i.e., the probable conditions which would bring about such a break, an elevated temperature tensile fracture would be expected to show the very high order of ductility shown by this service fracture. There is, of course, ample evidence of elevated temperature. Establishing the actual temperature at the time of failure is quite another matter.

The time element is a most important, but completely unknown factor in this event. Time influences the breaking strength, and the microstructure of both the steel and the galvanized coating. For the purpose of mechanical testing, it was assumed that the fracture process and exposure to elevated temperature involved a shorter time than days or hours, but a longer time than seconds or fractions of seconds. On this assumption, it is felt that the increasing temperature-constant load test performed is a reasonable simulation of the service failure, and that the temperature of 675°C (1250°F) should be reasonably close to the temperature in the fracture area at the time of failure. The slightly greater reduction in area in the service fracture suggests either the time at temperature was longer or the temperature was higher than in the tensile test.

Microstructural features of the bolt shank established approximate temperature limits for the service fracture although the limits are widely spaced. Recrystallization of hot-deformed iron requires a temperature in excess of 460°C (860°F)*. Variations in material composition, time, etc., between the service failure under consideration and the test work which established the above figure would, of course, lead to a discrepancy in the minimum recrystallization temperatures in the two cases. However, this discrepancy would probably not be so large as to invalidate the use of 460°C (860°F) as an approximate minimum service failure temperature. The fact the recrystallization was not complete and that some evidence of deformation persists immediately adjacent to the fracture indicates the temperature did not exceed the lower critical transformation temperature of 720°C (1330°F). An accurate assessment of the actual temperature reached within this 260C° (470F°) range depends upon information, especially elapsed time, which is not available. However, assuming a time at high temperature to be of the order of a few minutes, a failure temperature between 650°C (1200°F) and 705°C (1300°F) is probable.

Changes observed in the galvanized coating provide clear evidence for the localization of the elevated temperature to a maximum of under 3-1/2 in. from the fracture, and indicate a sharp rise in temperature in the immediate vicinity of fracture. The changes in structure indicate a probable maximum temperature of about 650°C (1200°F) on the surface of the bolt at 1/4 in. from the fracture.

While no particular item is definitive in itself, the findings are consistent with each other and indicate a highly localized zone of high temperature. A temperature in excess of 425°C (800°F) probably was confined to a length of less than 2 in. The maximum temperature was probably in the range of 650°C (1200°F) to 705°C (1300°F), with a most probable maximum of 675°C (1250°F).

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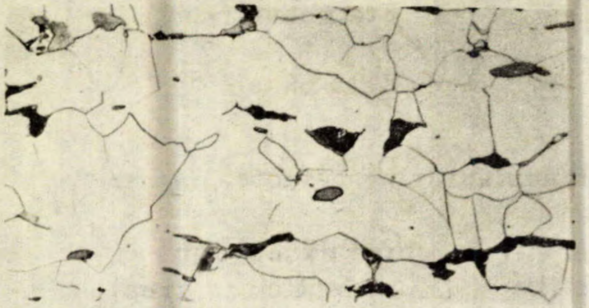
* ASM Handbook, 1948 Edition, page 262.

CONCLUSIONS

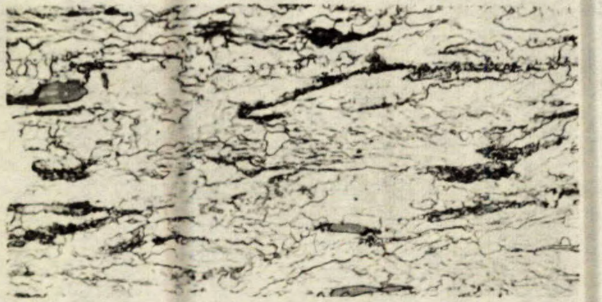
1. There was no evidence of manufacturing defects.
2. The fracture is a typical tensile fracture except for the very high degree of ductility (90% reduction in area).
3. The extreme reduction in area is characteristic of tensile failure at moderately elevated temperature.
4. The elevated temperature was restricted to a short length of the bolt.
5. The maximum temperature was estimated to lie in the range of 650°C to 705°C (1200°F to 1300°F) with a most probable maximum of 675°C (1250°F).

DRB: ac

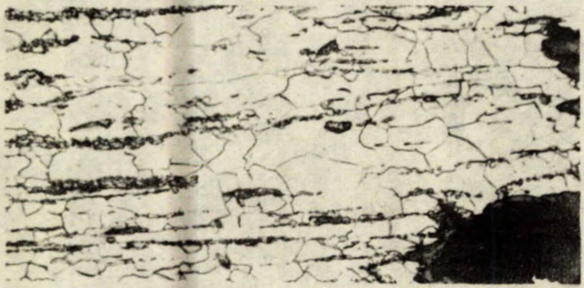


(a) Adjacent to bolt head.

(b) 1/2 in. from fracture.

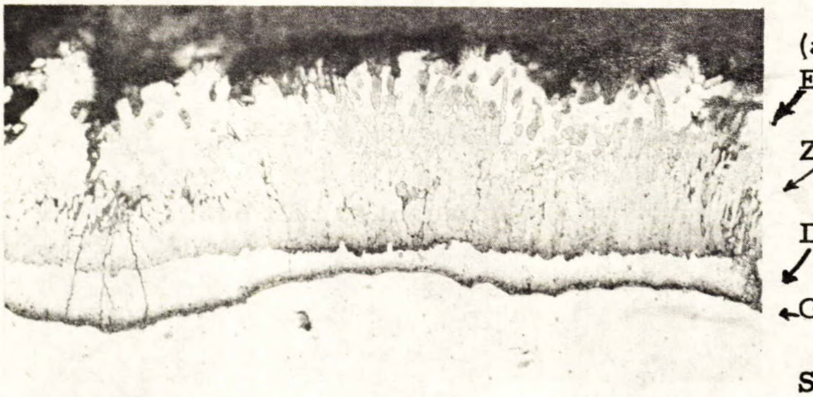


(c) 1/4 in. from fracture

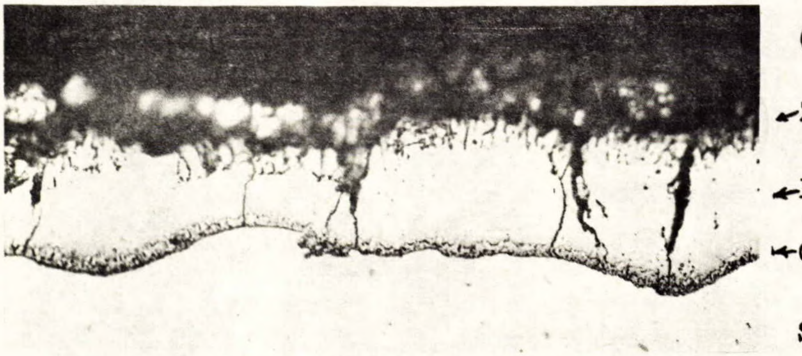


(d) Fracture

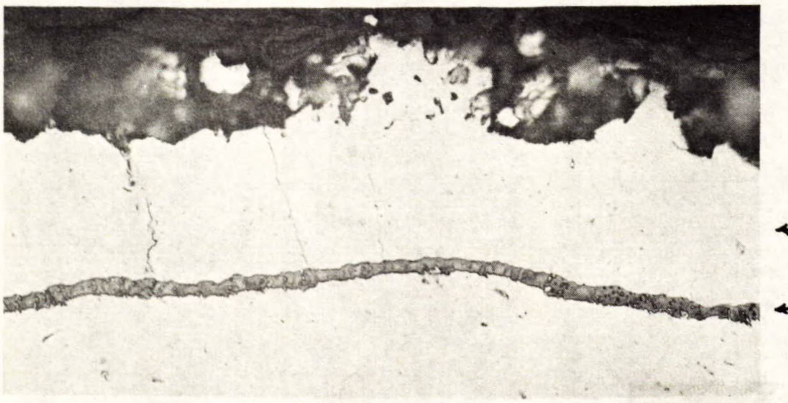
Figure 1. Longitudinal sections of bolt shank. Etched in 2% nital. All X500.



(a) 3-1/2 in. from fracture



(b) 1 in. from fracture



(c) 1/4 in. from fracture

Figure 2. Transverse sections of bolt shank, illustrating the change in the galvanized coating. Rowland's etch, X500.