Report on Fractured Eyebolt

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Conclusions

1. Both the fractured and whole eyebolts are of medium carbon cast steel.
2. The bolt failed suddenly in a completely brittle manner. No signs of fatigue failure were found.
3. Steels of the eyebolt composition have limited energy absorption in impact testing at room temperature.
4. An eyebolt of the design and composition of the failed bolt is unsuitable for the use to which the latter was put.
5. Low energy absorption in impact testing found in steel from the whole bolt and cracking in the thread roots of the failed bolt indicate that the bolts may have defects in material or workmanship.

General

On June 19, 1980, in the company of a number of concerned people, I visited [redacted] High School. There I examined the part of a fractured eyebolt still extending from the ceiling of the gymnasium. On July 10, 1980, I again visited the school to witness the bolt being removed from the ceiling. A nut and two washers were removed from the bolt-segment, and an attempt was made to unscrew the segment with a pipe wrench. This attempt was abandoned, as the wrench was causing excessive damage to the threads. Finally, the bolt was sawed off close to the concrete beam it extended from, giving an approximate 1" length of the 3/4" bolt for study. The fracture surface was almost entirely undisturbed by the removal operations. A similar bolt was screwed out of the ceiling for study and comparison with the fractured bolt segment. The bolt segment and whole bolt and the associated hardware are shown in Figures 1 and 2.

It was agreed that we three experts would do a cooperative investigation, and exchange all objective results.

[Redacted] was responsible for:

- Macrographs of all items of evidence
- Impact test on section of the whole bolt
- Metallography on wiole and fractured bolts
- Hardness tests on fractured bolt
- Chemical analysis of whole and fractured bolt
- Tensile test on section of whole bolt

Fractography was performed at Massachusetts Institute of Technology on the AMR-100A scanning electron miscroscope under the joint supervision of the three experts.

Results

Chemical analyses of the two bolts are given in Figure 3. The analyses are equivalent, and characteristic of a medium carbon cast steel. The whole eyebolt is clearly a casting, and the fractured bolt (the eye end of which was misplaced in an earlier investigation) was so identified in a 3 May 1979 Skinner and Sherman Report.

Figures 4 and 5 show the microstructures of the two bolts. Both bolts show the ferrite-pearlitic microstructures characteristic of steels of their composition. The two photomicrographs show no evidence of excessive porosity or other casting defects.

Figure 6 is an overall view of the fracture surface of the failed bolt. The surface appears to have tiny facets, which are characteristic of a brittle fracture.

Figure 7 is a scanning electron micrograph of a typical region of the fracture surface. The fracture here and over the rest of the surface is totally brittle, with no signs of ductility. No fatigue striations were found. Figure 8 is a scanning electron micrograph, showing a crack at a thread root on the failed bolt.

A number of similar cracks were observed in thread roots.

The results of a tensile test on the whole bolt are given as Figure 9. [Redacted] reported the hardness measurements of the fractured bolt of R_B85, 86, 88, and 93.

A room temperature Charpy test on a section of the whole bolt gave 100% brittle fracture at 2.25 ft-lbs.

Discussion

There are two questions to be answered:

1. Does the bolt contain defects in materials and/or workmanship?

2. Is a bolt of this type suitable for the use it received in the gymnasium?

Concerning (1), the composition (Figure 1), microstructure (Figure 4), strength and ductility (Figure 7), and hardness are all appropriate for a medium carbon cast steel. No macroscopic flaws in material or workmanship were observed in either bolt. The room temperature Charpy Impact energy absorption of 2.5 ft-lb (on the whole bolt) is rather low. Steels of this composition are expected to have about 30 ft-lb energy absorption at room temperature. However, evergy absorption measurements characteristically show a great deal of scatter, so the low value may or may not be significant.

The one serious indication of defects in materials or workmanship is the thread-root cracking seen in Figure 8. Such cracks should not occur in a steel as ductile as the eyebolt is supposed to be. Such cracks will propogate during use and tend to give the brittle fracture observed. An un-cracked, un-notched sample will show the kind of ductile failure reported in Figure 9. There are several possible causes for this root cracking. First, it could have occurred during use in the gym. This seems unlikely, as the threads were inside the nut, and would have been largely protected from the bending stresses exerted by people swinging from the rope. The stresses exerted during removal could hardly cause the cracking, either. If the root cracks did not occur during use, they probably occurred during threading, either due to brittle material or improper machining. Steel castings are supposed to be given a stress-relieving anneal before being used. A casting which had not been given a proper anneal would tend to be brittle and crack more easily. Improper threading practice - such as the wrong speed or lubricant - could give high local heating or stresses and produce cracking.

The second question concerns whether a bolt of the composition, manufacture, and design of that in Figure 2 is suitable for the use it received in the gym roof. The answer is clearly no. The problem is not very much with the bolt being a casting, since cast steels have approximately the same ductility as wrought steels. The main problem was in using a steel of this high a carbon content with sharp notches (the threads) under combined impact and fatigue loading. As noted, steels of this com- position have limited energy absorption in impact at room temperature. Thus, using this eyebolt with sharp notches at the threads was inviting brittle failure. By contrast, mild steels of 0.1% carbon show a high degree of energy absorption to about -50°F, far below room temperature. An eyebolt of the configuration seen in Figure 2, made of mild steel, would have been suitable. However, a slightly larger diameter bolt might have been needed to give the required strength.

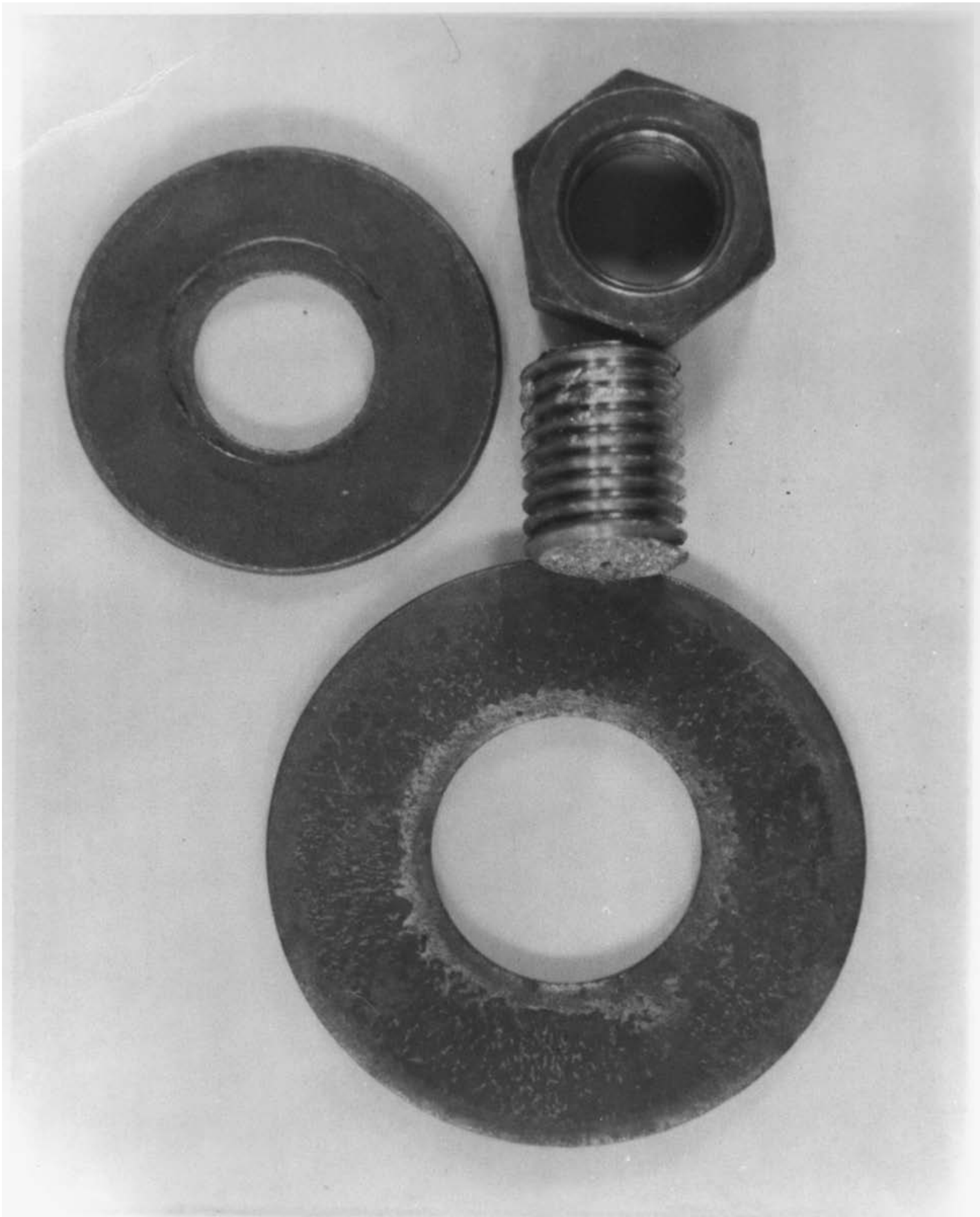

Figure 1: End of fractured eyebolt and associated hardware.

Figure 2: Whole bolt and associated hardware.

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NONDESTRUCTIVE EXAMINATION
METALLURGY AND FAILURE ANALYSIS

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HINGHAM, MASS. 02043

REPORT OF CHEMICAL ANALYSIS

Customer Donald G. Guay v Project Adventure
P.O.
Method
Date September 18, 1980
Description of Sample Sample 1: Fractured Bolt
Sample 2: Adjacent complete eyebolt
Job No. 0711

ELEMENT		SAMPLE 1	SAMPLE 2
Iron	Fe		
Vanadium	V		
Aluminum	Al		
Phosphorus	P	.012	.013
Sulphur	S	.018	.021
Silicon	Si	.161	.197
Titanium	Ti		
Copper	Cu		
Maganese	Mn	.73	.74
Nickel	Ni		
Chromium	Cr	.066	.065
Cobalt	Co		
Lead	Pb		
Molybdenum	Mo		
Tungsten	W		
Tantalum	Ta		
Niobium	Nb		
Tin	Sn		
Magnesium	Mg		
Zirconium	Zt		
Carbon	C	.368	.382

ELEMENT		SAMPLE 1	SAMPLE 2
Hydrogen	H		
Nitrogen	N		
Oxygen	O		
Boron	B		
Bismuth	Bi		
Silver	Ag		
Zinc	Zn		
Beryllium	Be		
Cadmium	Cd		
Gold	Ag		

③

Figure 3. Chemical analyses of whole and fractured bolt.

Date September 18, 1980
Subscribed and sworn to before me this 18th day of September 19 80
Nancy D. Baker
My commission expires 7/25/86
NOTARY PUBLIC

SIGNED Kenneth H Baker

Figure 3: Chemical analyses of whole and fracture bolt.

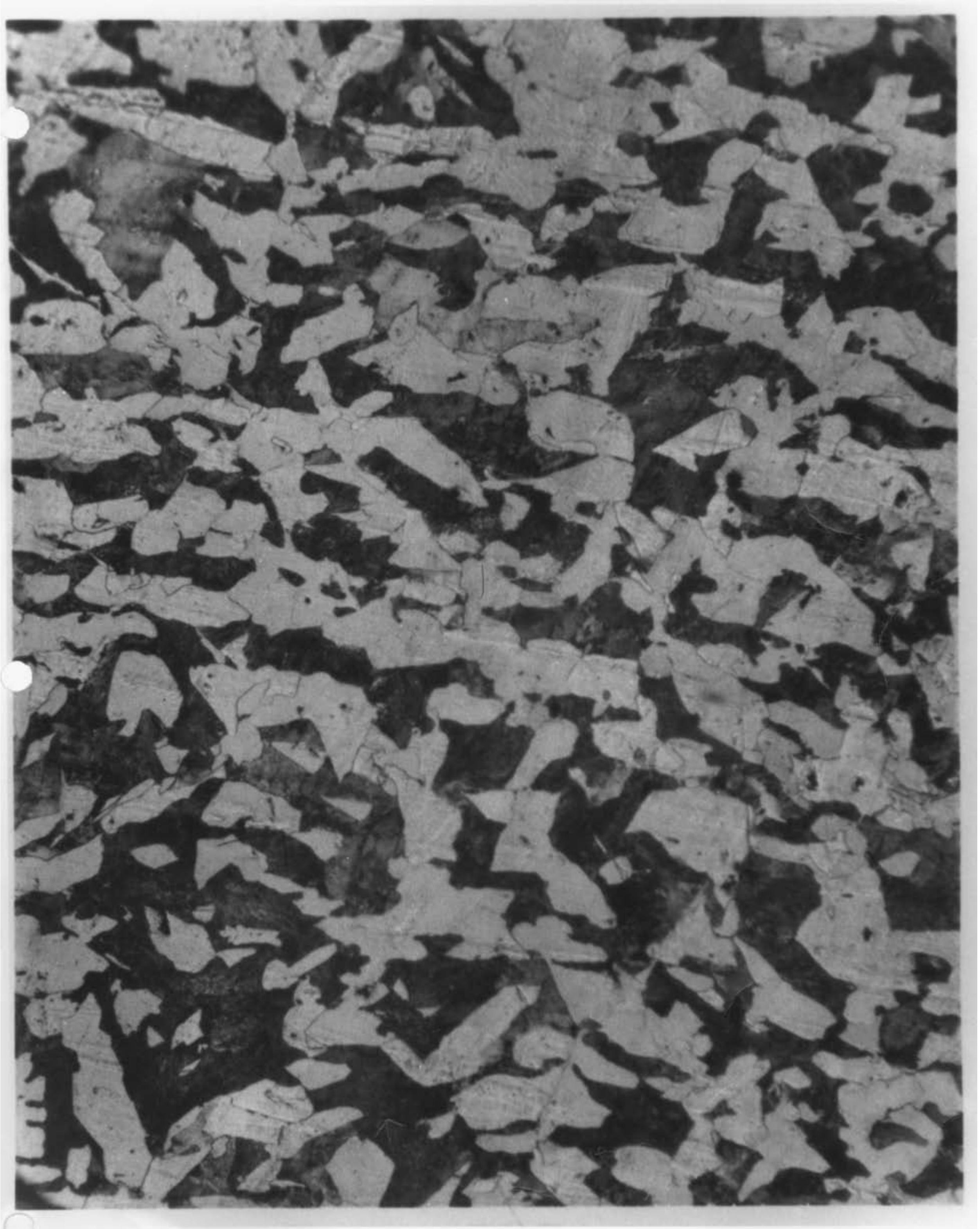

Figure 4: Microstructure of fracture bolt. (Transverse view, 200X)

Figure 5: Microstructure of whole bolt. (100X)

Figure 6: Overall view of fracture surface of failed bolt.

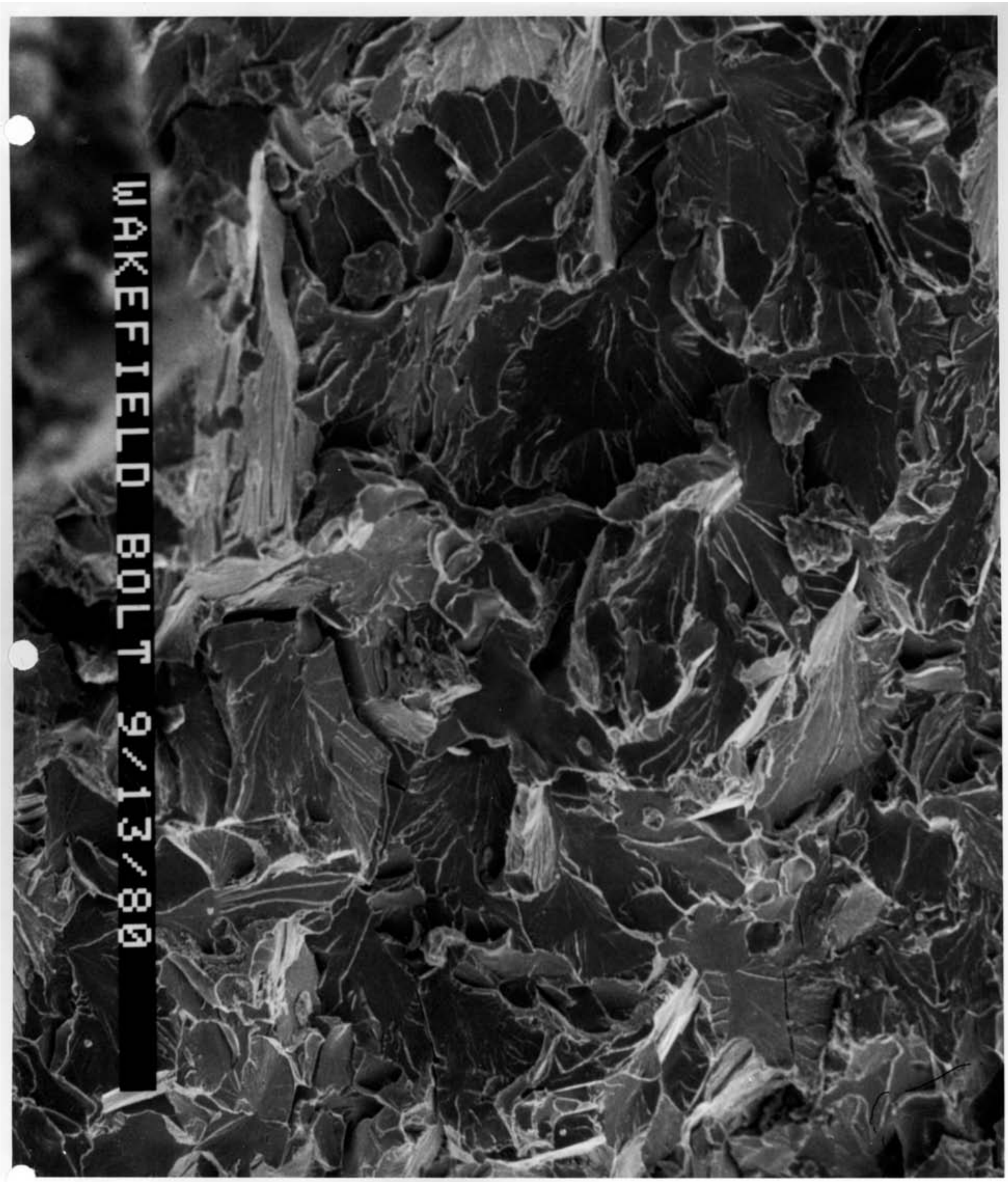

Figure 7: Scanning electron micrograph of typical region of fracture surface. (320X)

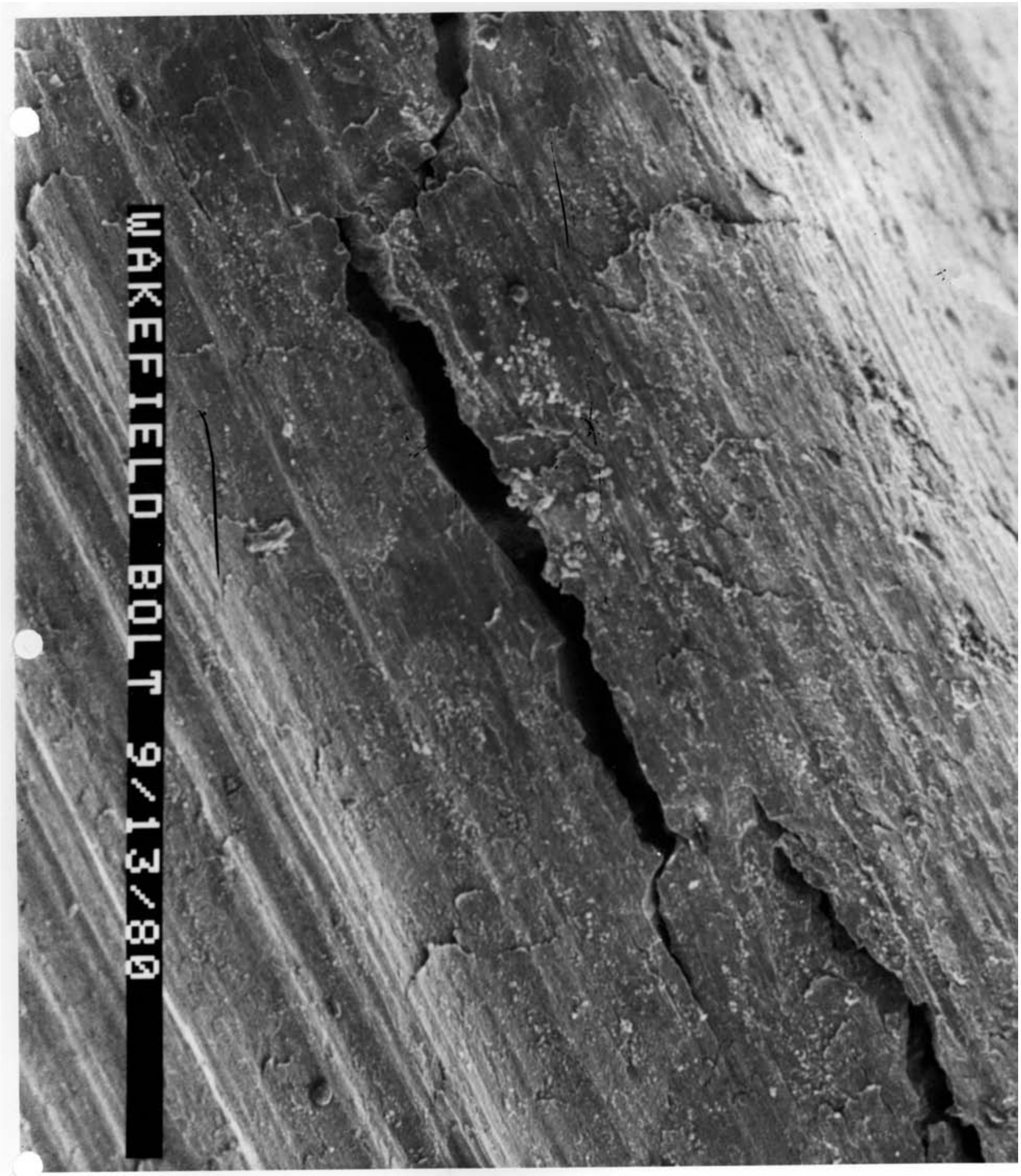

Figure 8: Scanning electron micrograph showing cracks at thread roots in failed bolt. (200X)

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RESULTS OF TENSILE TESTING

Customer Donald G. Guay v Project Adventure

Date of Testing September 16, 1980

Purchase Order

Heat No., WPS or Other Identification Complete Eye Bolt from Wakefield High School

Serial Number of Testing Machine Tinius Olson #58809-4

Calibration Date of Testing Machine

Code or Specification ASTM

Location of Specimens Shaft of eye bolt

Type of Specimens Standard Tensile

Specimen No.	Dia. or Width	Thickness	Area	Ultimate Total Load Pounds	Ultimate Unit Stress P.S.I.	Yield P.S.I.	Red. Area %	Elong %
1	.505		.200	20,000	100,000	58,750	30.0	18.1

We certify that machining, testing and observed results are correct and in accordance with the above specified codes and/or specifications. Per [illegible]

Date September 18, 1980

Subscribed and sworn to before me this 18th day of September 1980.

[illegible]

My commission expires 7/25/86

Figure 9. Results of Tensile test on sample from whole bolt.

Figure 9: Results of tensile test on sample from whole bolt.