CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

OTTAWA

MINES BRANCH INVESTIGATION REPORT IR 66-86

METALLURGICAL EXAMINATION OF WELLAND CANAL LOCK GATE ANCHOR PIN

by

D. R. BELL AND D. A. MUNRO

PHYSICAL METALLURGY DIVISION

COPY NO. 13

1867 1967

DECEMBER 30, 1966

Mines Branch Investigation Report IR 66-86

METALLURGICAL EXAMINATION OF WELLAND CANAL LOCK GATE ANCHOR PIN

by

D. R. Bell* and D. A. Munro**

- - -

SUMMARY OF RESULTS

Two broken 10-inch diameter lock gate anchorage pins from the Welland Canal were examined. The pins had been in service for 34 years, in the course of which they had worn and been repaired by welding and re-machining. The normal service stresses were very moderate. Breakage had occurred subsequent to nearby blasting in the winter months.

Fracture face markings were characteristic of brittle fracture. There was no evidence of fatigue cracks. Considerable cracking had occurred in the weld metal and the under-lying heat-affected zone of the parent metal. Examination showed considerable segregation. The silicon content was well below a satisfactory level for the carbon-manganese balance. Tensile, fatigue, and Charpy V-notch impact properties were determined. The impact properties were extremely poor. Despite the metallurgical deficiencies, it was considered that the most damaging feature was the weld cracking.

It was recommended that replacement pins be made of a low alloy machinery grade of steel and that all possible precautions be taken to guard against cracking if any weld repairs should be carried out in the future.

*Research Scientist and **Technician, Ferrous Metals Section, Physical Metallurgy Division, Mines Branch, Department of Energy, Mines and Resources, Ottawa, Canada.

INTRODUCTION

An examination of two 10-inch diameter by 24-inch gate anchorage pins was requested by the Western Region of the St. Lawrence Seaway Authority in a letter of 22nd February, 1966. The pins were received on 11th March, 1966. The findings of the examination, complete with illustrations, were forwarded by letter dated 6th June, 1966.

The following information was requested:

1) Chemical composition.

2) Physical properties, including endurance limit under repeated stresses.

3) Possible changes in grain structure on the fracture plane; skin versus core.

Drawings were submitted as follows:

a) The general plan for the 82 foot high gate leaf showing the location of the pin.

b) Mitering lock gates showing the assembly of the pins in the anchorage eyebar.

c) A stress sheet.

d) A drawing of the dimensional details of the pins.

It was stated the pins had been in service for approximately 30 years. Some may have been replaced but there was no record to that effect. The original pins were made of forged steel but the chemical composition could not be established. The pins had worn and had been built up by welding and machining to size. Neither preheating nor post-weld annealing had been carried out. Bending, bearing, and shear stresses were given as 12.9, 4.2, and 2.7 kpsi, respectively. Each pin had undergone approximately 154,000 operating cycles since installation in 1932.

In recent years, extensive modifications were made to lock structures involving blasting in areas adjacent to the lock gates. Since the blasting was invariably carried out in winter months it was considered quite conceivable that the shock loadings transmitted to the gate structures through frozen ground may well have contributed to the ultimate failure of the pins. This assumption was based on the fact that both fractured pins were found in gates close to areas where severe blasting took place during the 1964-65 winter.

VISUAL EXAMINATION

Examination of the fracture surface showed no evidence of fatigue crack markings. The features were characteristic of brittle fracture. The chevron markings showed a single point of fracture initiation, Figure 1. Longitudinal cracks were evident on the surface of the pin in the area of fracture origin, Figure 2.

METALLOGRAPHY

Deep etching in hot 1:1 HCl and water, and sulphur printing, of a full transverse section showed a high degree of heterogeneity, Figure 3. Flow lines in a deep etched partial longitudinal section showed the pin had been forged rather than rolled, Figure 4.

Microexamination revealed numerous cracks in both the weld metal at the surface and in the heat-affected zone in the parent metal, Figure 5. The general microstructure consisted of rather coarse-grained ferrite and pearlite characteristic of normalized, medium-carbon steel.

MECHANICAL PROPERTIES

Tensile tests were carried out on two standard specimens, 0.505 in. diameter, 2 in. gauge length, with results shown in Table 1.

TABLE 1

Tensile Test Results

Sample	Ultimate Strength, kpsi	Yield Point, kpsi	Elongation in 4 x Dia., %	Reduction of Area, %
1	79.5	40.0	23.5	41.3
2	87.1	44.8	20.0	37.3
Average	83.3	42.4	21.8	39.3

Fatigue tests were carried out in rotating bending with unnotched R.R. Moore specimens. Results are given in Table 2.

TABLE 2

Fatigue Test Results

Sample	Applied Stress, psi	Number of Cycles to Failure
1	35,000	---- (Bent)
2	30,000	10,526,000
3	32,000	15,173,000
4	34,000	225,000
5	33,000	468,000

Longitudinal Charpy V-notch impact tests were carried out with the results shown in Table 3.

TABLE 3

Results of Charpy V-Notch Impact Tests

Sample	Test Temperature, °F	Absorbed Energy, ft-lb
1	+120	10
2	+120	8
3	+120	10
4	+180	19
5	+180	22
6	+180	20
7	+212	22
8	+212	22
9	+212	21

A microhardness survey from adjacent to the surface through the weld metal and the heat-affected zone into the parent metal, was carried out using a Knoop diamond indenter with a 500 gram load. Results are shown in Table 4. The Knoop hardness results are shown in addition to the equivalent Rockwell values.

TABLE 4

Results of Microhardness Survey

Distance from Surface in inches	Hardness	
	Knoop	Rockwell
0.020	229	96B
0.060	229	96B
0.140	247	99B
0.180	247	99B
0.200	331	33C
0.240	277	25C
0.260	331	33C
0.300	281	25C
0.340	212	92B
0.440	192	88B

CHEMICAL COMPOSITION

Drillings were obtained from a transverse section at edge, mid-radius and near-centre locations, for chemical analysis. Drillings from the three locations were mixed to obtain a representative sample. Amounts of all elements were determined by wet chemical methods. Results are shown in Table 5.

TABLE 5

Chemical Composition
Per Cent of Element

Carbon	Manganese	Silicon	Sulphur	Phosphorus
0.54	0.42	0.07	0.027	0.007

Nickel, chromium, molybdenum, and vanadium were present in residual amounts only.

COMMENTS

With regard to the three specific queries, the chemical composition and mechanical properties have been given in detail above; the only significant change in grain structure on the fracture plane is that adjacent to the surface associated with weld repair.

The silicon content is much below usual commercial practice and suggests this pin was made from steel from an over-oxidized heat. Such material can be expected to have inferior notch ductility. The degree of heterogeneity is excessive by normal commercial standards. Despite these metallurgical deficiencies the pins stood up to the normal service requirements for an extended period of time.

Given the combination of an impulsive load (of unknown magnitude) low temperature, the notches formed by the extensive weld cracking, and the poor notch toughness of the steel, brittle fracture would be expected. In fact, the notch toughness of the steel was so low that brittle fracture would be expected if the same abnormal loading had been applied in the summer.

The lack of incipient fatigue cracks, despite the presence of ideal nucleation sites in the weld cracks, suggests the normal service stresses are very low. However, the number of stress cycles since the weld repair had been made is not known and fatigue cracking might have developed over a longer period.

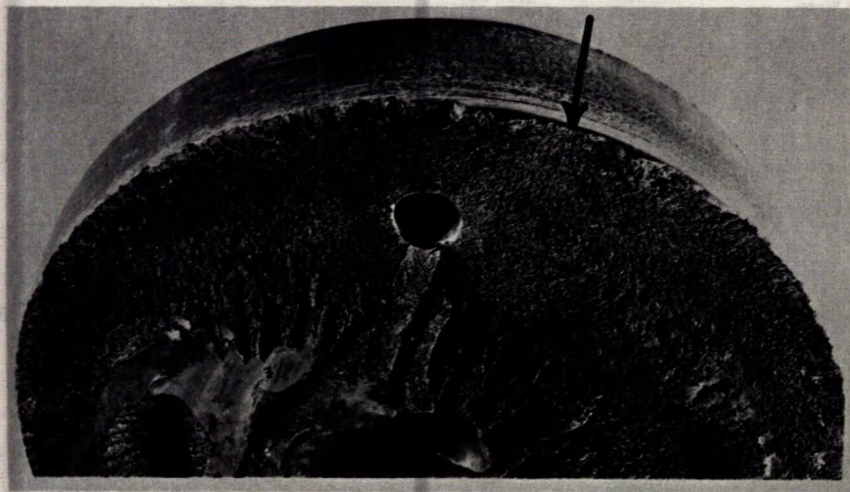
In considering the degree of hazard from the various deficiencies and stresses, first place must go to the weld cracks. The sharp notches so formed constitute the best crack starters for brittle fracture, and are potent fatigue crack initiation sites. It is recommended that all possible precautions be taken in future to guard against cracking, including under-bead cracking, when weld repairs are carried out. Even the relatively modest mechanical properties of this pin may have been sufficient to give extended further service in the absence of such severe defects.

RECOMMENDATIONS

1. Replacement pins be made of a low alloy machinery grade of steel such as Atlas Ultimo 200.

2. In the event of repair welding of any nature, great care be exercised to ensure the successful employment of the precautions required to guard against cracking.

DRB:DAM:bb

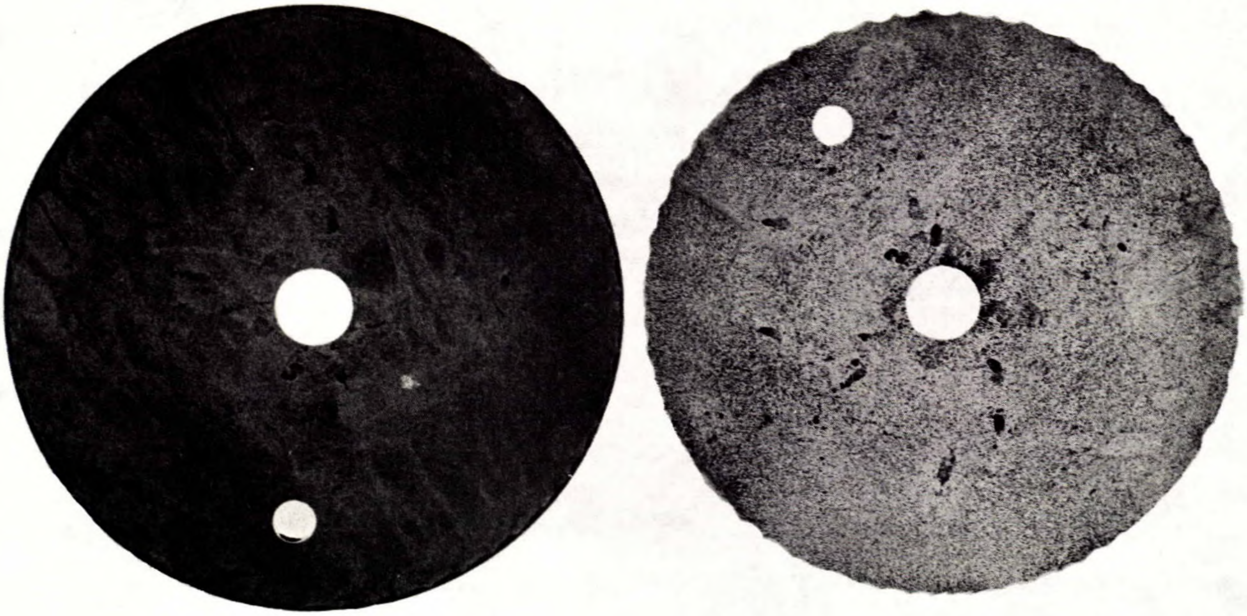


Approximately 1/2 Full Size

Figure 1. Oblique view of fracture face. Arrow shows origin of fracture.

Approximately Full Size

Figure 2. Surface of pin at fracture origin. Note longitudinal cracks.



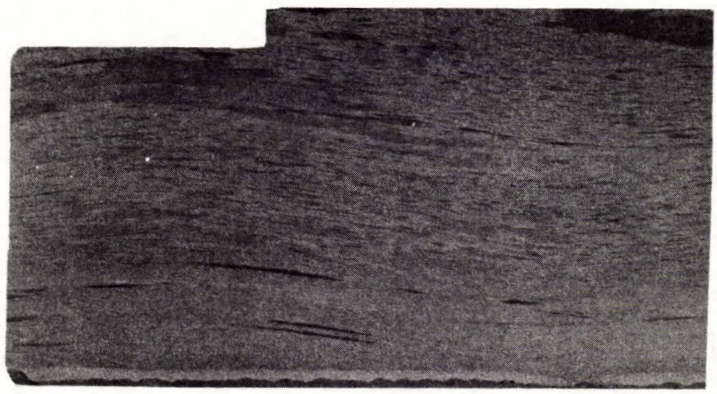
(a) (b)

Approximately 1/3 Full Size

Figure 3. Full transverse section adjacent to the fracture.

(a) Shows results of deep etching in hot 1:1 HCL and water.
(b) Is a sulphur print of the same section.

Both show a high degree of heterogeneity.



Approximately 1/2 Full Size

Figure 4. Half longitudinal section, deep etched in hot 1:1 HCL and water. Curved flow lines indicate the material had been forged rather than rolled. Again, marked heterogeneity is evident.

(a) Weld metal.

(b) Weld metal at top and heat-affected zone of parent metal at bottom.

(c) Parent metal.

X100, etched with 2% nital

Figure 5. Transverse section adjacent to the fracture origin. Note the severe cracking in the weld metal, (a), extending into the under-lying heat-affected zone (b).