Failure Analysis of An Angle Bracket of A White Liquor Sludge Rake

*Grewal G., Singh S., and Tiwary R.K.

**Pal S.S. and Gaur P.K.

ABSTRACT

Mild steel angle brackets are used as structural components in white liquor clarifiers. Under normal operating conditions, sudden failure of this component is known to occur only in the presence of gross transient overloads on the system. However, in the course of its service life, the angle bracket is known to undergo steady erosion driven reduction in net section area, which eventually leads to failure by loss of structural integrity of the component. However, a recent catastrophic failure of an angle bracket could not be correlated with either of these two mechanisms. A detailed investigation reveled that the component had undergone failure by the nucleation and penetration of stress corrosion cracks in a zone of maximum constraint in the component.

INTRODUCTION

In a white liquor clarifier, rotating rakes are used for removing the settled particulate sludge from the bottom of the tank. The ploughs and buckets used in a typical rake are structurally attached to radial cantilever type booms which are in-turn joined to the central main drive shaft by a truss like deployment of tie rods. The tie rods are structurally attached to each other as well as to other components using mild steel angle brackets. Welding and bolting operations are used for ensuring optimal rigidity and proper load transfer in these components.

The white liquor clarifier environment comprises of a relatively high concentration of caustic (causticity in the range 75-80%) at a temperature of about 100°C[1]. Though, in the presence of this environment, carbon and mild steels are prone to stress corrosion cracking[2,3,] this phenomenon is not usually encountered because of the below-threshold extraneous stresses imposed on the rake unit. Hence, under the usual operating conditions, a typical angle bracket has a virtually infinite fatigue life and usually undergoes failure by the mechanism of erosion driven reduction in net section area. Sudden failures of the component are also known to occur under the unusual conditions of gross extraneous overloads on the system.

Recently, however, in a white liquor clarifier unit operating in a major integrated paper mill, an angle bracket underwent catastrophic failure after a few months of operation. It was first suspected that the angle bracket may have failed by over-stressing due to excessive loading of the rake unit. However, visual examination of the fracture surface clearly ruled out the possibility of failure by this mode. A subsequent failure investigation revealed that the angle bracket had undergone failure by a mechanism not usually encountered under the usual normal operating

*Thapar Corporate Research and Development Centre,
Bhadson Road, P.B. No. 68,
Patiala-147 001(Pb)
**Ballarpur Paper Mills,
Ballarpur Industries Ltd.,
Dist. Chandrapur-442 901 (M.S.)

Table 1
Wet Chemistry of Bracket Material

Element	Mass percent
C	0.14
Mn	0.80
Si	0.10
S	0.062
P	0.058

conditions found in the white liquor clarifier. Details are presented in the following sections.

WET CHEMISTRY AND MECHANICAL PROPERTY EVALUATION

The component material was first subjected to a confirmatory chemical and mechanical property analysis. The results of the wet chemical analysis are shown in Table 1. Based on these results, the composition of the bracket was confirmed as mild steel.

Next, to determine if the bracket material had adequate load bearing properties, the tensile properties were determined using the standard practice for sub-scale tensile testing. For the purpose of testing, one number sub-scale specimen was machined from the bracket, in a region located far away from the fracture surface, and subjected to tensile testing in the Hounsfield tensometer. Based on this test, the tensile strength was determined as 557 MP a with a elongation value of 16%. These results conform to typical values reported for mild steel. The hardness of the bracket material was also determined using the sub-scale Brinell hardness test. Based on a number of indentations, the average hardness of the bracket was determined as BHN 163±5. This hardness value is also a typical number reported for mild steel.

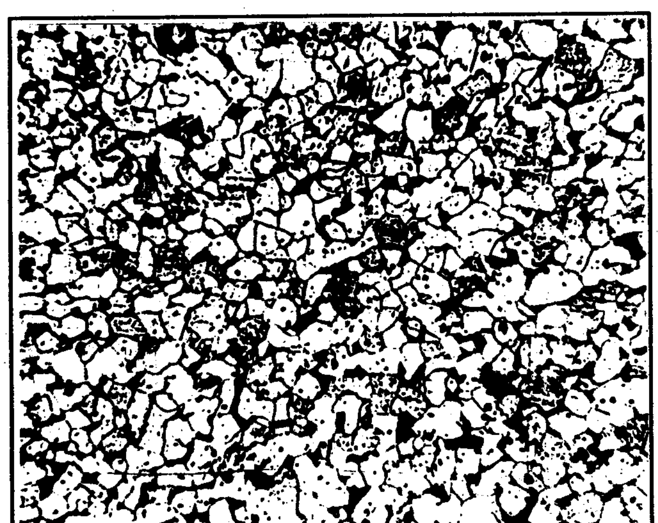

Fig-1: An optical micrograph showing the microstructure of the angle bracket material, M = 100X.

METALLOGRAPHY

Since, the wet chemistry and the mechanical properties of the angle bracket material were found to conform to specifications, it was suspected that the component may have undergone failure by the mechanism of stress corrosion cracking and/or corrosion fatigue. To determine the presence of possible intergranular cracking, the region close to the point of failure was prepared using standard polishing and etching techniques and examined under an optically microscope. This examination revealed the presence of extensive stress corrosion cracking. Typical micrographs obtained are shown in Figs. 1-3. Specifically, the ferritic-pearlitic microstructure of the component material is shown in Fig. 1, while the presence of an extensive networking of stress corrosion cracks are imaged in Figs. 2-3. Note the extensive characteristic branching[4] of the cracks in both these micrographs. The micrograph shown in Fig. 2 corresponds to the L-W plane (principal plane) while the third micrograph is taken in the W-T orientation (thickness plane). Note that the stress corrosion cracking has propagated completely across the thickness direction. Isolated island of the base material completely circumscribed by stress corrosion cracks are also clearly evident in both these micrographs.

Fig-2: An optical micrograph showing the presence of stress corrosion cracking on the L-W plane, M = 200 X.

Fig-3: An optical micrograph showing the presence of stress corrosion cracking on the W-T plane, M = 200 X.

CONCLUSIONS

The microsopic evidence obtained clearly indicates that the failure of the angle bracket occurred by nucleation and propagation of stress corrosion cracks. It is conjectured that the over-constraining of the angle bracket during the welding operation resulted in a significant residual stress in the component. This residual stress was further augmented by relatively higher stressing of the rake due to the presence of a thick, relatively immobile, layer of sludge on the tank bottom. The combined stress then resulted in the operating stress intensity factor to exceed the threshold stress intensity factor for stress corrosion cracking as a consequence of which the component underwent premature failure. The conclusions obtained in this investigation singularly highlight the critical role of design and optimal fabrication methodology in environments prone to stress corrosion cracking. Clearly, for such environments, the design safety factors should be significantly higher than the standard recommended factors available in engineering design handbooks.

REFERENCES

1. Private Communication, BILT-Ballarpur, 1998.
2. Fontana M.G., "Corrosion Engineering, McGraw Hill Book Company, Third Edition, Singapore, 1986, p. 109.
3. Dieter G. E., Mechanical Metallurgy, McGraw Hill Book Company, New York, 1998, p. 492.
4. Craig B., "Environmentally Induced Cracking", ASM Metals Handbook, Vol. 13, 9th Edition, ASM International, Metals Park, Ohio, 1987, p. 145.