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Failure analysis of the multistage de-scaling pump impeller of the hot strip mill plant

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Abstract - *Premature failure of the multistage descaling pump impeller of hot strip mill (HSM) has been investigated. The multistage centrifugal pumps are used in hot strip mill for a large variety of applications, such as roll cooling, strip cooling at run-out table and de-scaling. The impeller is a single piece casting of martensitic stainless steel. The impeller rotates at 4800 rpm with a volumetric flow of 400 m^3/hr of flue water with a discharge pressure of 185-210 bar. The premature failed impeller has been thoroughly investigated to find out the root cause of the failure. The investigated includes visual examination, chemical analysis, hardness measurement and optical microscopy and electron probe micro analyzer (EPMA).Visual examination of the failed impeller indicated that the crack originated at the vane curvature and the presence of fatigue. The purpose of the investigation was to find out the root cause of impeller blade failure and suggest possible measures, to avoid the failure in future. The investigation results revealed that erosion, fatigue stress and material degradation were found to be the prominent reason for the impeller failure.*

Key words: Impeller1, Martensitic stainless steel2, Cast3, EPMA4, Erosion4 and Fatigue stress6

1. INTRODUCTION

Centrifugal pumps are a sub-class of dynamic axisymmetric work-absorbing turbomachinery used to induce flow or raise pressure of a liquid. Centrifugal pump consists of a rotating five stage impeller inside a stationary volute (casing). The impeller is fastened to the shaft. The shaft passes through the pump casing and out through the stuffing box (portion of the casing through which the shaft extends and where seal or packing is placed). The shaft is supported by two bearing housings and is connected by a coupling installed between the pump shaft and the motor shaft [01]. Impeller has a series of curved vanes fitted inside the shroud plates. These vanes are backward curved. Backward curved vanes have the blade angle less than 90 degrees [02]. A pump configuration may vary depending on the fluid-flow direction that can be radial, semi-axial or axial. Axial flow pumps achieve larger flow rates than radial pumps and are used in drainage control, power plants and process cooling [03]. Figure 1 (a) shows a front view of multistage centrifugal pump. Any pump operation is determined by the flow rate Q (m3/h), the water discharging pressure P_2 (bar) and impeller revolutions n (min−1). The design and operation of a pump also depend on the operational efficiency, the stability of the head-capacity characteristic, vibration and noise. An important issue is a possible pump failure due to fatigue, cavitations, hydro abrasive wear or erosion. Cavitation is the removal of material from the surface by formation and rapid collapse of bubbles of gas or vapor in an adjacent liquid. This type of wear is somewhat unique as only one metal surface is involved. The basic mechanism is true pitting fatigue, resulting in pits on the surfaces of the impeller. High-speed flow of liquid in these devices causes local hydrodynamic pressures to vary widely and rapidly. This resulting pit can be quite small or very large and deep depending on the particular circumstances [04]. Cavitation pitting is caused by rapid and repetitive movement between the metal and the liquid [04]. Most centrifugal pumps are out of sight during the operation and, for this reason, it is important to monitor the shaft vibrations and other operational parameters [03]. The average life of the impeller is 5 years while the stainless-steel impeller failed in the 2.5 years of the service. The impeller was a single cast made up of the grade AISI 414 martensitic stainless steel. This stainless-steel grade was a material of choice because of its good corrosion and erosion-resistant properties. In present studies, premature failure investigation of the impeller was carried out. The pump is working in the area of hot rolling mill for de-scaling of the strip. The centrifugal-pump operating parameter were maintained as, water flow rate Q = 400 m3/h, inlet pressure of water P_1 = 5 bars, discharging pressure P_2 = 200 bars and the number of revolutions n = 4800 min−1. The pump assembly was dismantled for investigation. The damaged impeller is shown in figure 1 (b).

Fig-1 (a) A multistage centrifugal pump

Fig-1 (b) Damaged impeller

2. OBSERVATIONS, RESULTS AND DISCUSSION

The failure analysis of the damaged impeller includes visual observations & on-site information, physical, chemical, mechanical and microscopic examinations.

2.1. Visual examination

Visual examination of the damaged impeller revealed that the crack originated at sharp edge or other stress raisers, crack first initiates and then propagate to critical size, at which time sudden failure occurs. The fatigue life consists of crack initiation and propagation. On the other hand, when fatigue failures are caused by inclusion or pre-existing crack-life defects, the entire life consists of crack propagation. Such situations are commonly encountered during service failure [08].The stainless-steel impeller as shown in Figure 1(b) was a curve-shaped vane with a diameter of 305 mm. Figure 2 (a) and 2 (b) show that the material loss due to erosion and the cavities was observed.

Fig- 2 (a) Full view of impeller sample refers for analysis:

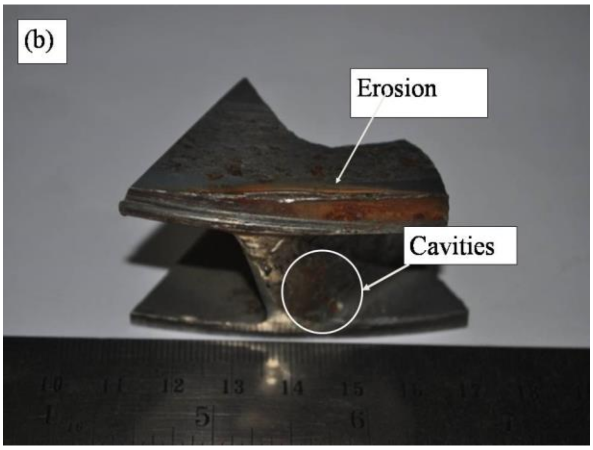


Fig- 2 (b) Erosion and cavities

2.2. Chemical analysis

The chemical composition of the impeller material was determined by Optical emission spectroscopy (OES) and the results are given in Table 1 along with the specified chemical composition. The analysis revealed that the impeller material is a martensitic stainless steel [09]. The actual chemical composition shows carbon, silicon and manganese somewhat on the lower side.

Table-1: Chemical-composition comparison in mass fractions (w, %)

Elements, %	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Cu
Pump impeller	0.0925	0.357	0.762	0.008	0.007	12.06	0.27	1.12	0.069	0.073
AISI-414	0.15	1	1	0.04	0.03	11.5-13.5	-	1.25-2.5	-	-

2.3. Mechanical Testing

A hardness value of the machined impeller sample is presented in Table 2 and sample as shown in Figure 3. The brinel hardness was evaluated as per the standard ISO 6506-2:2005 [10] in Wolper Wilson instruments, model 930N having ball indentation ball size 2.5 mm with weight applied 187.5 kg. The measured hardness values are found to be much lower than that of the specified standard value for the equivalent AISI-414 grade.

Table-2: The bulk hardness, Brinell (BHN) values measured across the samples

Sr. No.	Obtained Hardness	Specification AISI-414
Point 1	227.1	459 (BHN) (UTS= 1555 MPa)
Point 2	227.4	
Point 3	229.4	
Point 4	232.5	
Average	229.1 (BHN) (UTS=772 MPa)	

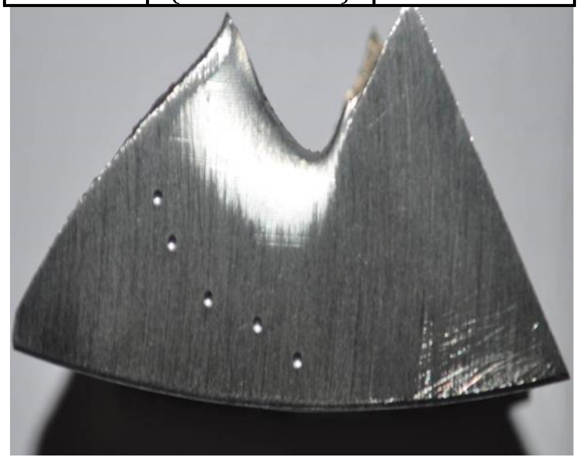


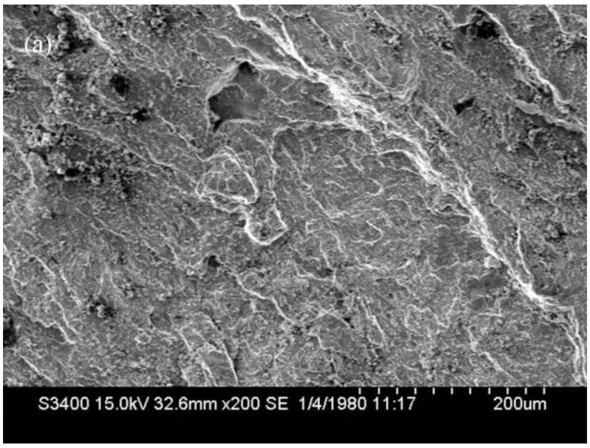
Fig-3: sample for hardness test

The estimated value of tensile strength (772 MPa) of impeller is found much lower than that of the specified standard tensile strength of 1555 MPa [11].

2.4. Fractography Analysis

The fractography analysis was carried out extensively using Electron Probe Micro- Analyzer (EPMA/ EDS) in JEOL 8230 at 200x to find out the mode of failure as shown in figure 4 (a) and the composition of the precipitates at the grain boundaries as well as in certain spots within the matrix as shown in Figure 4 (b) and the results is tabulated in Table 3.

It is observed that the Precipitation of chromium was observed along the grain boundary as shown in Fig. 4



(b).

Fig-4: (a) Surface of brittle cleavage fracture

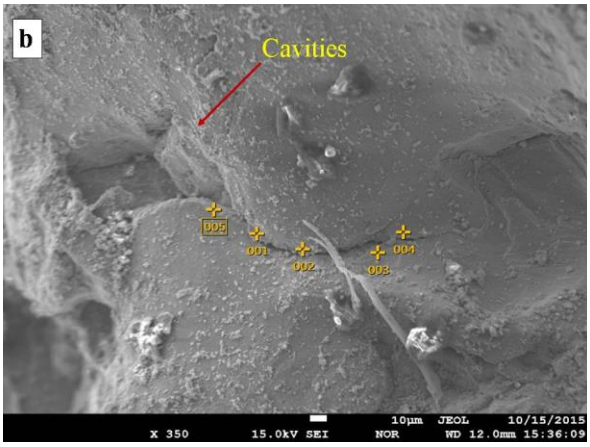


Fig-4: (b) EPMA image of fracture surface

The EPMA examination of the fracture surfaces was identified as a mixed fracture mode of brittle cleavage and fatigue rupture.

Table - 3: EPMA/EDS Analysis (wt. %)

Spectrum	P	Fe	K	O	Na	Mg	Al	Si	S	Ca	Cr	Mn	Ni	Total
Point-1	nd	25.78	nd	34.96	nd	4.38	1.63	0.34	nd	0.83	31.46	nd	0.61	99.99
Point-2	0.36	2.34	nd	32.16	nd	nd	1.44	nd	nd	nd	43.85	19.86	nd	99.65
Point-3	0.74	27.89	nd	52.04	3.69	0.03	nd	7.01	nd	1.03	5.14	2.43	nd	99.26
Point-4	nd	24.36	nd	50.05	nd	1.99	0.73	nd	nd	5.45	17.42	nd	nd	100
Point-5	0.56	34.07	1.83	37.78	2.42	0.29	nd	2.73	nd	nd	15.9	4.32	0.09	99.43
Max.	0.74	34.07	1.83	52.04	3.69	4.38	1.63	7.01		5.45	43.85	19.86	0.61	
Min.	0.36	2.34	1.83	32.16	2.42	0.03	0.73	0.34		0.83	5.14	2.43	0.09	
Average	0.55	22.89	1.83	41.4	3.06	1.67	1.27	3.36	0	2.44	22.75	8.87	0.35	
Deviation	0.19	12.07	0	9.06	0.9	2	0.47	3.38		2.61	15.05	9.56	0.37	

2.5. MICROSTRUCTURE

Metallographic samples were prepared as per ASTM E 1078-02 [12] standard and the etchant used was 4% nital solution for microstructure examination. Microstructure examination was carried out by using a Carl Zeiss Optical microscope at a magnification of 1000X. The microstructure consists martensite in uniform distribution of ferrite matrix as shown in figure 5.

Fig-5: Optical images taken at 1000X of impeller sample

3. DISCUSSIONS

The examination procedure described was performed to determine the mechanism of a premature failure of the multistage centrifugal pump impeller. The pump functioned during the de-scaling of the strip. The impeller rotates at 4800 rpm with a volumetric flow of 400 m3/hr of flue water with a discharging pressure 185-210 bar. Visual observation of the failed component reveals at sharp edge or other stress raisers, crack first initiates and then propagate to critical size where erosion and the cavities observed, the formation of cavities & erosion because of variation of a pressure and turbulent flow inside the casing. The chemical analysis confirms that the impeller material is a martensitic stainless steel; the actual chemical composition shows carbon, silicon and manganese somewhat on the lower side as can be seen in table-1. The universal hardness in Brinell scale at room temperature taken, the results of obtaining hardness values are lower than the specified standard hardness as seen in table-2. The fractography by EPMA showed as a mixed fracture mode of brittle cleavage and fatigue rupture. From the EDS analysis of the failed sample it is observed that there is a deposition of Cr along the crack line. The microstructure shows light contrast area is ferrite and dark contrast area is martensite phase. Thus premature failure of impeller happened from a fatigue crack through continued operation and changes in operational conditions.

4. CONCLUSION

After the examination, it is concluded that the most probable cause for the multistage centrifugal pump impeller failure are due to material properties degradation

5. RECOMMENDATION

Check the material properties and composition matches with the specified standard, and avoid the pressure variation inside the casing for future failure

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