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Failure Analysis of 9%Cr-Mo Steel Component

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ABSTRACT
This paper presents the fractographic characterization of 9%Cr-Mo Steel which was failed during service in fossil fuel fire stream power plant. The fractured surfaces as well as the surface of the failed component were examined by visual examination and in a scanning electron microscope at suitable magnification. The energy dispersive spectroscopy was performed to analyze the steel quality. EDS analysis has indicated the poor quality of steel used for manufacturing component. From the characteristics of the fractured surface it is concluded that it is a tension overload failure.
Keywords – EDS analysis, Fracture, Inclusion, 9%Cr-Mo steel, Torsion

I. INTRODUCTION

The quality of steel is the key requirement in any thermal power plant. It becomes more critical in fossil fuel fired steam power plant because of the stringent operating conditions and emission norms. These issues are usually tackled by increasing thermal efficiencies of power generating plants. Fuel can be conserved and hence less fuel is required for a given power output. This subsequently lower fuel consumption and hence lower emissions of environmentally damaging gases.

Increase in the thermal efficiency of a power plant can be most effectively achieved by increasing the temperature and to a lesser extent, the pressure of the steam entering the turbine. High steam temperature along with the high pressure makes the high quality steel grades for the boiler operations. Most modern steam power stations now in operation reach efficiencies of around 42% with steam temperatures of 600 ^{0}C and pressures of 25–30 MPa. The next generation of steam power plants should be capable of operating with steam at 625–650C, to enable thermal efficiencies of around 45% to be achieved [1]. Hence, the increasing operating temperatures and pressures impose increasingly stringent requirements on the materials of construction.

The increase in the thermal efficiency has provided the incentive for the development of the 9% chromium steels. Many reports are published on investigation of the properties of 9% Cr steel with respect to its application as a pipe work and boiler steel operating at elevated temperatures [2]. These steel provide improved creep rupture strength. The alloying additions such as chromium, molybdenum, tungsten, vanadium, niobium, etc enhance the properties required for high temperature applications. Chromium improves high temperature strength and increases oxidation resistance. Molybdenum increases the creep resistance. Presence of Nickel and Manganese in smaller quantities increases hardenability of the steel. Three such 9-12% Cr martensitic steels which are mostly used are ASTM Grades- P91 (9Cr-1Mo-V-Nb), E911 (9Cr-1Mo-1W-V-Nb) and P92 (9Cr-0.5Mo-1.8W-V-Nb) [3]. The chemical composition of these steel as per ASTM A335 is given in table-1.

Table-1 Chemical Composition of mostly used Cr-Mo Steel grades (As per ASTM A335)

Element	Composition		
	Grade P91	Grade P92	Grade E911
C	0.08-0.12	0.07-0.13	0.090-0.30
Si	0.20-0.50	Max 0.50	0.10-0.50
Mn	0.30-0.60	0.30-0.60	0.3-0.6
P	Max 0.020	Max 0.020	Max 0.020
S	Max 0.010	Max 0.010	Max 0.010
Cr	8.00-9.50	8.50-9.50	8.50-10.50
Ni	Max 0.40	Max 0.40	Max 0.40
Mo	0.85-1.05	0.30-0.60	0.9-1.10
V	0.18-0.25	0.15-0.25	0.18-0.25
N	0.03-0.07	0.03-0.07	0.04-0.09
Nb	0.06-0.10	0.04-0.09	0.06-0.10
Al	Max 0.02	Max 0.02	Max 0.04
Ti	Max 0.01	Max 0.01	Max 0.01
W	----	1.50-2.00	0.90-1.10
B	----	0.001-0.006	0.0003-0.0060
Other%	----	Zr Max 0.01	----

Component fails due to many reasons and failure that commonly occur in service depending upon their possible modes of failure are Overload, Distortion, Fatigue, Corrosion, Wear etc. Every structure has a load limit beyond which it is considered unsafe. An applied load that exceeds this limit is known as overload [4]. The nature of fracture arising due to overload failure could either ductile or brittle or a combination of the two. Fracture due to tension overload failure follows the 45^0 direction of maximum tensile stress. Fig.1indicate geometry of fracture of torsion overloads failure of ductile and brittle material.

Torsion overloads failure depends on the condition of the material, geometry of the member, types and rate of loading and temperature conditions. Ductility of the steel component decreases by increasing the strength of the metal by heat-treatment or cold working; sources of stress-concentration such as notches fillets, holes, scratches, inclusions, porosity, etc; increasing rate of loading and decreasing the temperature.

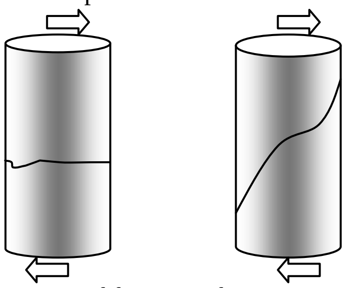


Fig.1 Geometry of fracture of torsion overloads failure

The objective of this study was to examine the fracture surface of 9% Cr-Mo steel and to carry out fractographic analysis and tried to find out the root cause of the failure.

II. EXPERIMENTAL PROCEDURES

The material under investigation was received after failure from fossil fuel fired steam power plant for investigation. The detailed metallurgical investigations were carried out on the fractured sample which included visual examination of fractured surface and near area of failed component. Microstructure analysis by scanning electron microscope at different magnifications and elemental analysis by EDAX were carried out.

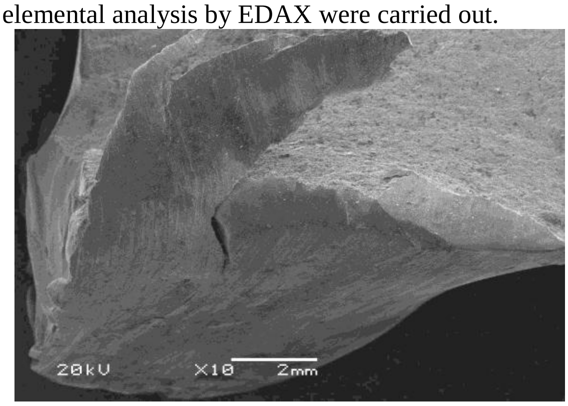


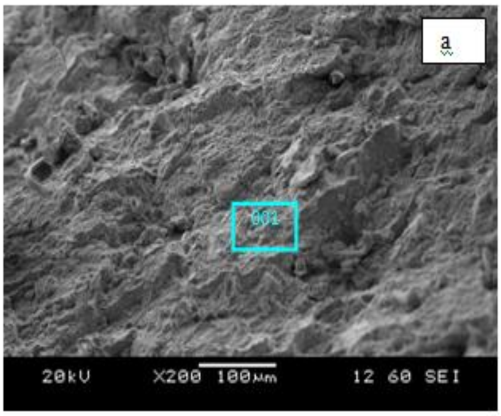
Fig. 2. Photograph of fractured surface at 10 X magnification

1. Visual Examination

Visual examination of the sample revealed a generally smooth surface with small amount of deformation. However, the fractured portion of the sample revealed a brighter shiny surface typical of brittle fracture. The fractured sample is shown in the fig.2 at 10X. It is observed that the fracture follows the 45^0 direction of maximum tensile stress. A spiral type fracture surface of a brittle material can be clearly seen from the image presented in fig.2. The macroscopic investigation of the failed component did not show any surface abnormality and confirms to specification.

2. Scanning electron microscopy

The scanning electron microscopy was performed using a JEOL SEM model JSM 6380A with an energy dispersive system. It is equipped with a light element detector and software for quantitative chemical analysis. Different fractured surfaces are shown in the SEM figures 3a, 4 and 5 at higher magnifications. Surface shows irregular bright facets of a cleavage type. SEM image at 3a is enlarged at 250X magnification and presented in fig. 4 indicate the presence of some foreign particles inside the steel. The size of the foreign materials embedded in the material are about 15-25 µm in diameter. The presences of foreign materials are suggestive indications for the possible reasons for the failure.



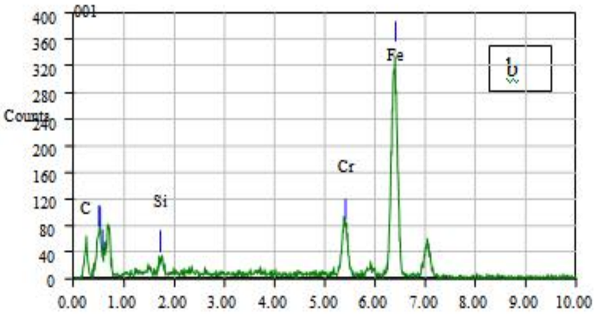


Fig 3. a. SEM photograph of the fractured surface at 30X with the b. EDS spectrum taken on the fractured surface

These suggestive indications are further analyzed at higher magnifications and presented in figs. 4 and 5. It confirmed the presence of foreign material or inclusion in steel which is subsequently analyzed by EDS analysis.

3. EDS observation

The Energy Dispersive Spectroscopy (EDS) spectrum of the entire scan area is displayed in digitized form with the x-axis representing X-ray energy. The ZAF standardless Qualitative Analysis indicates the presence of chromium about 8.5-9 mass% in the matrix. It shows the intense peak of iron and small peaks for the Silicon, Aluminium, etc.

The Energy Dispersive Spectroscopy (EDS) spectrum of the selected area is displayed in digitized form with the x-axis representing X-ray energy. The EDAX analysis by ZAF Method Standardless Quantitative Analysis of the fractured surface shows the presence of major constituent elements such as Silicon, Aluminium, Chromium and also the Oxygen as shown in Fig. 6a and 6b.

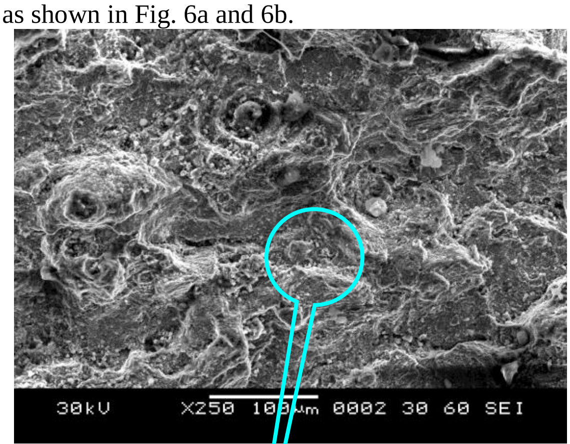


Fig. 4 SEM photograph of fractured surface at 250X magnification

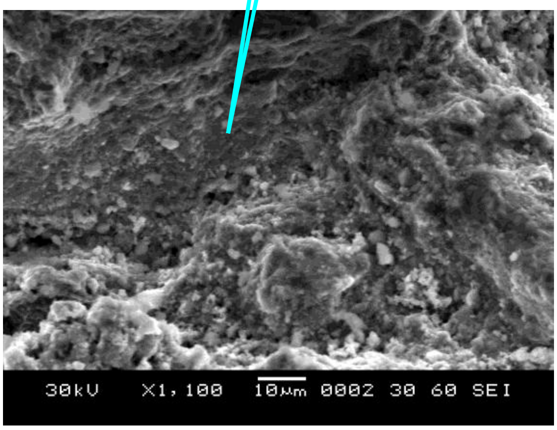


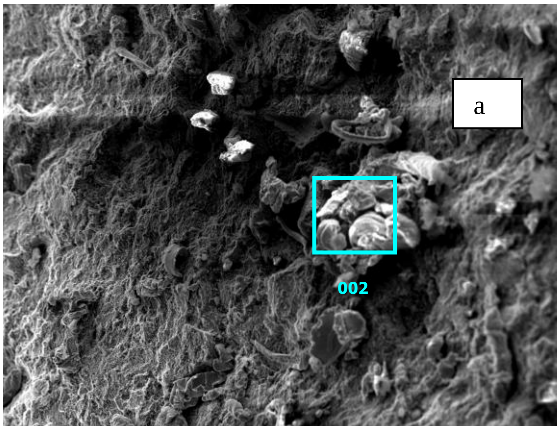
Fig. 5 SEM photograph of fractured surface at 1100X magnification

It shows intense peak of iron and also peaks for the Silicon, Chromium, Aluminium and Oxygen. Oxygen peak is comparatively strong as compare to the other three elements. This indicated that the fractured surface may have the oxides of iron, chromium, silicon and aluminum. This can be seen from the EDS graph as shown in fig.6b.

III. RESULTS AND DISCUSSIONS

The fractured portion of the sample revealed a brighter shiny surface typical of brittle fracture. Presence of cleavage step including feather marks and fine grained fractured surface is indicative of brittle fracture. Fracture follows the 45^0 direction of maximum tensile stress. A spiral type fracture surface of a material is the indication of the torsion load acted on the component. These indications are usually obtained in torsion overload failure.

The EDS analysis by ZAF Method Standardless Quantitative Analysis of the fractured surface indicate the presence of major constituent elements such as Silicon, Aluminium, Chromium and Oxygen as shown in Fig. 6a and 6b. It shows the major peak of oxygen and chromium. This indicated that the fractured surface may have the oxides of iron, chromium, silicon and aluminum. This lowers the strength of the material. As the applied load exceeds the fracture strength of the material which is lowered due to the presence of inclusion, component failed in brittle manner.



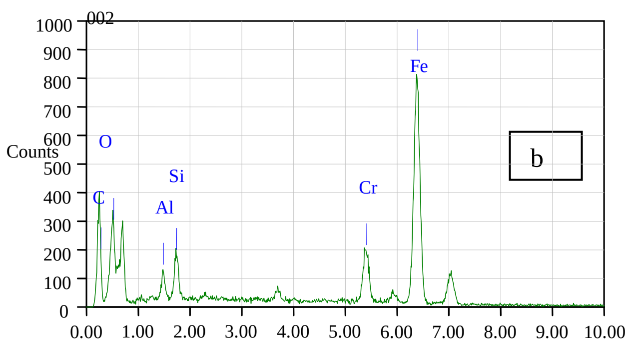


Fig. 6a SEM photograph of fractured surface indicating the area of inclusion with the b. EDS spectrum taken on the inclusion

IV. CONCLUSION

From the above observation, we can conclude that the component failed in brittle manner. This is a torsion overload failure. The strength of the material is lowered due to the presence of the non metallic inclusions. Failure originated as the applied load exceeds the fracture strength of the material.

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