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Shaft Failures in Coal Handling Plants

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ABSTRACT

An analysis of premature failures in coal pulveriser mill shafts brings out the facts that the auxiliary units, in a power plant, like coal feeders, pulverizer mills *etc.*, do not receive much attention during routine inspections and lack in property specification for the materials. It is brought out in this investigation that mere specification of material composition and hardness is not enough for load bearing components operating under cyclic loads.

INTRODUCTION

Power plants may often require shut downs owing to failures in auxiliary units like coal feeders, pulveriser mill etc. A majority of these failures occur in the mechanical power transmission systems like gears and shafts [1-4] which operate under a variety of loads such as tension, torsion, bending or a combination of these. In all of the references cited, the failures had similar features like, a fatigue crack initiates and further grows till reaching a critical length upon which, the components fail due to over loads. The fatigue cracks typically originate from high stress concentrators like changing cross sectional areas and keyways that are imminent in shafts. In few cases it was even found that the repairs attempted on the components, by welding the cracks, have also led to multiple crack initiation sites [5].

A number of coal pulveriser mill shafts have been reported to have failed within 8 000hr to 25 000hr of operation against a design life of 80 000hr [1, 2]. A typical investigation of failures in these shafts is discussed in this paper.

VISUAL INSPECTION

A schematic representation, of the shafts employed in coal pulveriser mills, is shown in Fig. 1.

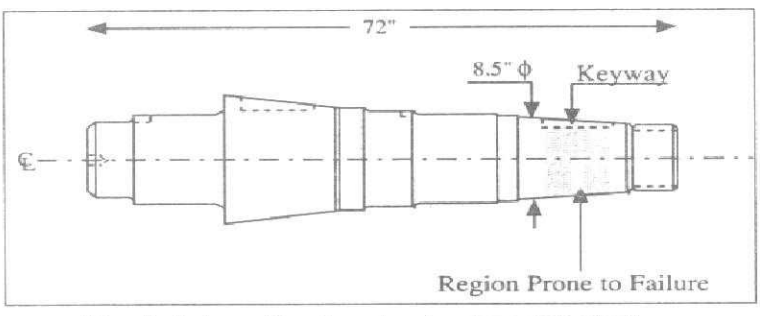


Fig. 1: Schematic of coal pulveriser mill shaft.

The shafts that were supplied included a few with deep fatigue cracks in them. The fatigue cracks were found to have originated from the key ways. A typical embedded crack was examined by ultrasonic technique and a profile was drawn as depicted in Fig. 2 [2]. Other material conditions permitting, it appears, this type of crack initiation from key way corners can be reduced by providing sufficient radius of curvature at the corners.

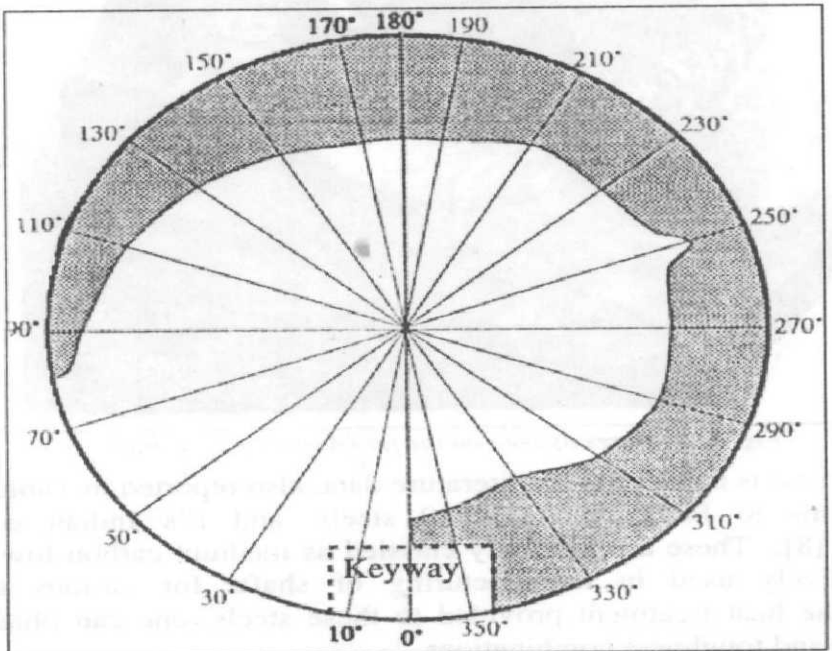


Fig. 2: A profile of embedded fatigue crack as traced by ultrasonic technique.

Presented in Fig. 3 is a photo macrograph of fracture surface of a completely failed shaft. It can be seen from the smoother portion (indicated as A) of the failure that the fatigue cracks have grown through 80% of the cross section before final overload failure (indicated as B).

COMPOSITION OF THE SHAFT MATERIAL

Material from several shafts was analysed for chemical composition and the average of these compositions is provided in Table 1.

Table 1: Chemical composition (wt%) of the shaft material

	C	*Mn*	*S*	*Si*	*P*	*Ni*	*Cr*	*Mo*
Shaft material	0.43	0.6	0.03	0.15-0.30	0.02	1.37	1.29-	0.43
En 24 [6]	0.35-0.45	0.45-0.70	0.05 max.	0.10-0.35	0.05 max.	1.30-1.80	0.90-1.40	0.20-0.35
AISI4340 [7]	0.38-0.43	0.600-0.80	0.04 max.	0.15-0.30	0.035 max.	1.65-2.00	0.70-0.90	0.20-0.30

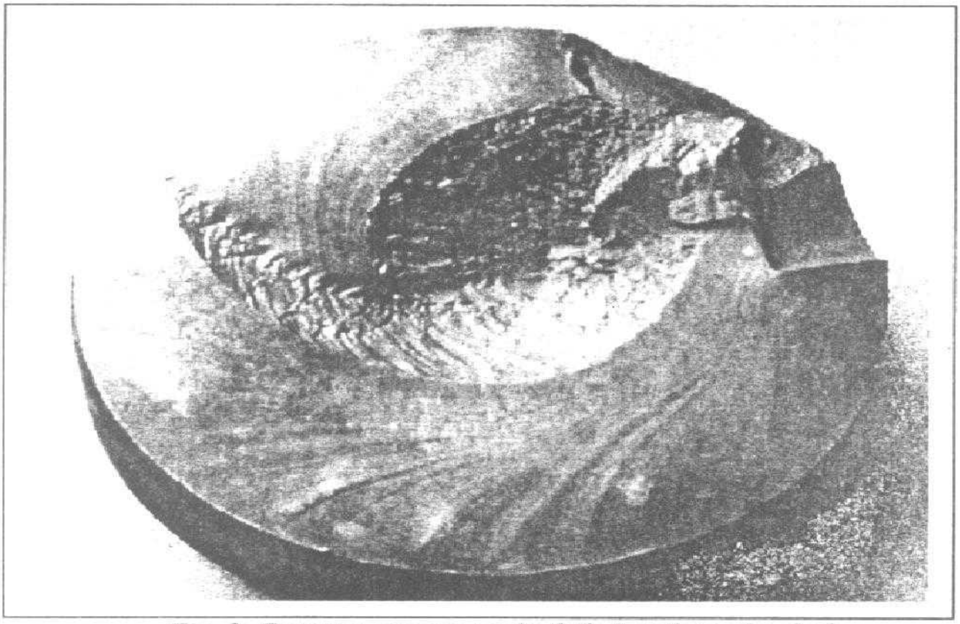


Fig. 3: Features as seen on the failed surface of a shaft.

When a coparison is made with the literature data, also reported in Table 1, the shaft material conforms to En24 or AISI4340 steels. and it's Indian equivalent is 40Ni2Cr1Mo28 [8]. These are generally classied as medium carbon low alloy steels and are extensively used in manufacturing of shafts for various applications. Depending on the heat treatment provided to these steels, one can obtain a widely varying strength and toughness combinations.

METALLOGRAPHY

Standard metallographic techniques were followed for examining the nature of inclusions and microstructure of the shaft material. The inclusions were found to be MnS type elongated along the flow lines (Fig. 4). However, the overall content and the length of the inclusions were felt to be not alarming. The microstructure reveals tempered martensite or bainite (Fig. 5) which is expected from the heat treated steels of this class. Further TEM that has been carried out showed presence of large carbides along the lath boundaries. (Fig. 6).

MECHANICAL PROPERTIES

Standard tensile specimens as per ASTM E-8M [9] and charpy V notch (CVN) toughness specimens as per ASTM E-23 [10] were machined from various locations of the shaft and were tested for routine mechanical properties. Shown in Table 2 are the average values obtained from these tests. Table 2 also shows the values reported in literature for various heat treated conditions of similar steels.

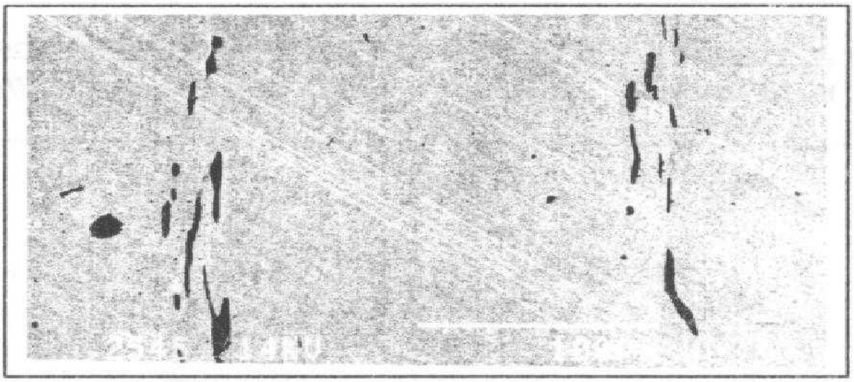


Fig. 4: Photomicrograph showing typical MnS inclusions along the flow lines.

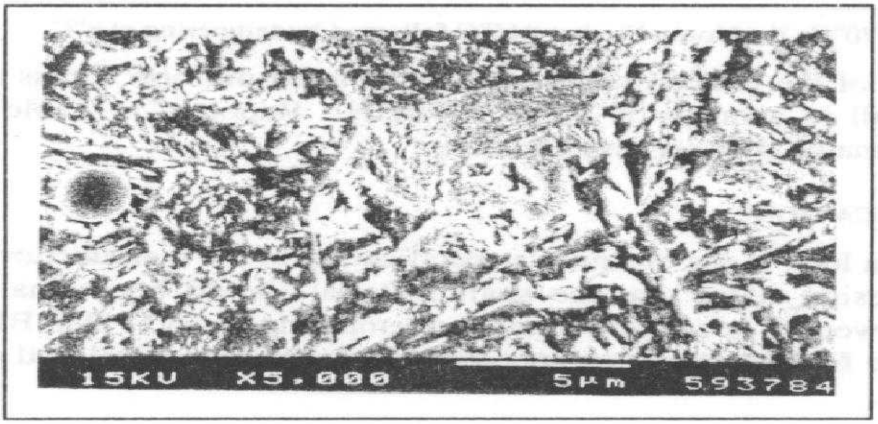


Fig. 5: Microstructure of shaft material showing tempered martensite/bainite.

Fig. 6: TEM micrograph showing carbides along lath boundaries

Table 2: A comparison of the mechanical properties of shaft materials.

Material	*Yield strength, MPa*	*Tensile strength, MPa*	*Hardness, BHN*	*CVN toughness, J*
Shaft under investigation	780	1110	385	14
AISI4340 [7]				
N870	860	1280	363	52
T315	1620	1760	490	14
T425	1365	1500	440	16
T540	1160	1240	360	47

N: Normalised at 870°C; *T*x: Normalised at 845°C followed by tempering at x°C.

The hardness of the materials has been found to be uniform across the diameter of the shaft and fall in a range of 375 – 395BHN. Reported in Table 2 is the mean hardness of the material under investigation.

DESIGN SPECIFICATION

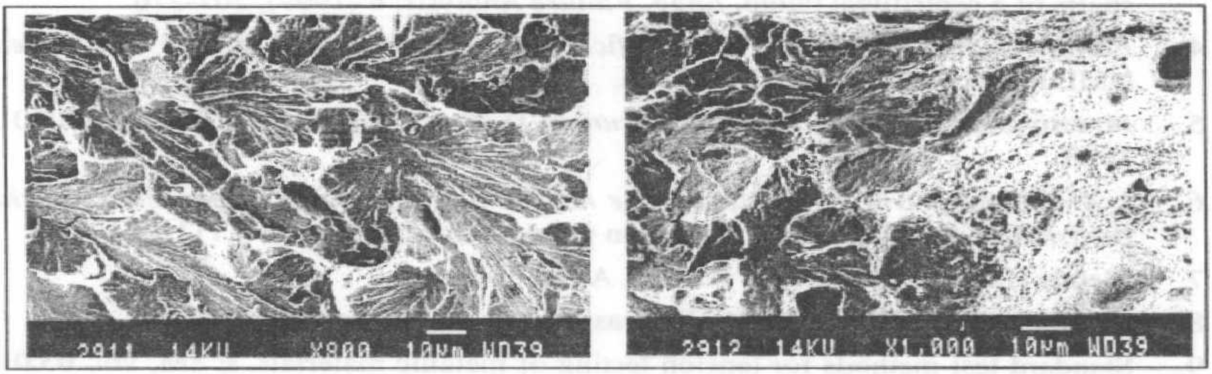
At this stage a look at the designer's specification to the manufacturer will be worth taking. The design states that the shaft material should be normalised and proof machined, followed by quenching in oil and tempering to 250 – 280 BHN before final machining. The forging ratios are specified as cast to bloom 1:4 and rolled bloom to final size as 1:2.

DISCUSSION

The chemical analysis reveals that the composition of the material employed for the application is appropriate. From the metallographic studies and the hardness survey it appears that the forging has been carried out as specified, because none of the inclusions formed were segregated and all of them were broken down as expected (see Fig. 4). However, the hardness specified is significantly below the values that were observed on the failed shafts. A comparison of the mechanical properties, taken from Handbook and reported in Table 2, shows that the combination of strength, hardness and toughness find a best match with the normalised condition of the steel. While the strength properties are generally adequate, the low toughness of the material makes it susceptible to premature failure through easy crack propagation through the brittle microstructures. These cracks could initiate from any of the mechanical stress raisers or inclusions.

The above discussion elicits that the shafts have failed prematurely due to low toughness. The low toughness of the steels is a result of improper heat treatment provided to the shafts.

A limited experimentation carried out on the shaft material consisted of tempering the shaft material to 650°C without re-solution treatment. It was found that the hardness dropped to 275BHN, bringing the value down to comply with the design specification. The CVN toughness value increased from 14J to 80J. A comparison of the fracture surfaces, of the impact test specimens, brings out the differences in the fracture mode of the specimens (Fig. 7) which changes from complete cleavage to ductile mode.



As received material showing cleavage fracture   Tempered material showing ductile fracture.

Fig. 7: Fractographs of impact tested specimens

It is interesting to state that based on the above investigation a power company, which had a number of pulveriser shafts in store, provided direct tempering treatment at 650°C to the shafts in stock. This has enabled the company to cut down significantly on the down-time of the coal mills and save substantially by not having to order for frequent replacements.

CONCLUDING REMARKS

While it is no doubt that the class of steels belonging to En24/AISI4340 are best suited to mechanical power transmission systems, care must be ensured while specifying the design requirements to the manufacturer. In these class of steels while the hardness does reflect the microstructure, it is not unique and the same hardness can be attained by several routes of heat treatment, not all of them producing optimum microstructures. Hence, it is recommended that the specifications should contain a minimum toughness requirement in addition to the hardness.

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