Supply of salvaged shafts as new ones: failure cases to study malpractices and their effects

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***Abstract* - Shafts are critical components of many machines, and a damaged shaft can hamper or halt production. When the alternate replacement is not available, in order to restore the production, shafts are repaired mainly either by depositing weld metal or spraying the metal. The weld deposition is a most commonly used methodology owing to its simplicity. Although this methodology is preferred to be only temporary replacement, many instances of misuse were found over the period of time. It has been applied to materials which are only weldable by special procedures, to the indiscriminate building-up of worn out components and for the correction of machining errors. Many failure investigations revealed that the suppliers have been using this technique to supply such repaired shafts to the organizations as a new piece. The recent analyses discussed in this papers includes failure of armature shaft of traction motor of a locomotive and earlier failures of roll shaft of CRM CGL and support roll shafts, etc. are the cases which proved that the shafts were supplied in repaired condition. The weld repair reduces the fatigue strength of the material. As, in most of the materials, tensile strength of the weld is lower than the base metal, these components have lower fatigue endurance. Salvaging of shafts by material deposition using thermal spray technique can be one of the alternatives to have repairs of shaft with better fatigue life but that too is acceptable for temporary repairs. Its misuse during supply of the material is still an issue for inspecting agency of an industry.**

***Index Terms* – shafts, failure, fatigue, welding, salvaging, deposition, fatigue strength, etc.**

I. INTRODUCTION

Shafts are rotating machine elements. Generally they have circular cross section. These are used for power transmission from one to another form or from energy producer to energy absorber. Shafts are either transmission elements or form an integral part of the machine. Considering their application, shafts are considered to be critical components in any machine. Shafts generally provide comparatively higher life and thus are not preferred element of inventory of any mechanical store in an industry. As they transmit power and motion to running components, their failure can lead to unavailability of the particular section or the entire unit. For locally manufactured shafts, the new shafts can be quickly procured replacing the failed shafts whereas for imported shafts or shafts made by long distance vendors, it may take very long time for procurement. In such cases, the failed or worn out shafts are weld repaired and machined to match the design dimensions and put to service in order to buy the time for procurement of new one.

The practices of weld repair apart from joining of the two parts are well known for weld deposition or thermal spray of the metals for ID or OD correction. Components like rolls, which primarily face compressive loads, are subjected to the practice of welding or thermal spray deposition for OD correction. When the alternate replacement is not available, in order to restore the productions, shafts are repaired mainly either by depositing weld metal or spraying the metal. The weld deposition is most commonly used methodology owing to its simplicity. Although this methodology is preferred to provide only temporary replacement, the ease with which metal can be deposited has led to many instances of misuse. It has been applied to materials which are only weldable by special procedures, to the indiscriminate building-up of worn components and for the correction of machining errors by ill-informed persons who are not aware of the possible outcomes where dynamic stresses are to be withstood in service [1]. Many failure investigations revealed that the suppliers have been using this technique to supply such repaired shafts to the organizations as a new piece.

II. THE FAILURE CASES

In this paper six prominent shaft failures will be discussed having common root cause of failure. The shafts failed in distinct units of the production facility. Table 1 summarizes the failure cases.

It can be clearly observed that all these failures took place at distinct locations. The life obtained compared to the expected life was also found to be very low. The hardness, microstructure and mechanical properties of all the material grades of these shafts are comparable with EN24 having highest strength (among the mentioned materials) owing to its chemistry followed by 42CrMo4 or 42Cr4Mo2, 55C8 and 45C8 according to application requirements.

Table 1: Overview of the failures investigated related to salvaging of shafts

Sr. No.	Year of Investigation	Component	Life Obtained/ Life Expected	Material of construction
1	2011	Shaft of HT Upper Bend pulley at Blast Furnace	07 months / NA	IS1570 42Cr4Mo2
2	2014	Rotor shaft of impactor of ternary crushing at washery	1.5 months / 10 years	DIN 42CrMo4
3	2014	Squeeze roll shaft for chromate roll at Continuous Galvanizing Line	3 years / 5 years	IS1875 45C8
4	2014	Support roll shaft of mixing drum at Sinter Plant	04 months / NA	IS1875 55C8
5	2014	Pulley shaft at sinter plant	05 years/ 15 years	IS1875 45C8
6	2015	Armature shaft of traction motor of Rail Locomotive	15 months/ 15 years	EN 24

III. VISUAL OBSERVATIONS

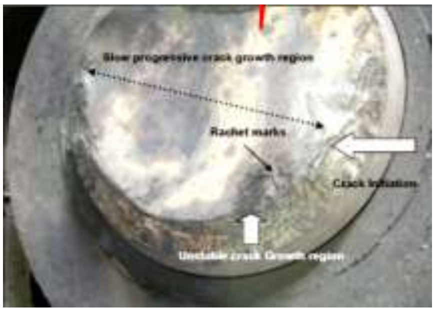

Fig. 1.1: Bend Pulley and its fracture Surface

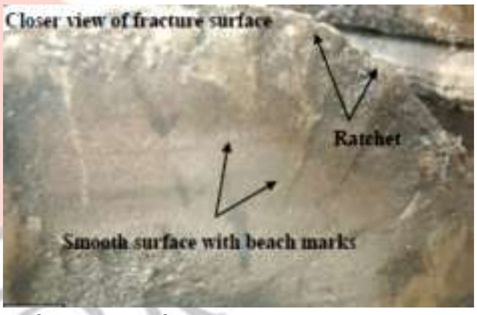

Fig. 1.2: Rotor shaft of impactor and its fracture Surface

Fig. 1.3: Squeeze Roll shaft and its fracture Surface

Fig. 1.4: Support Roll and its fracture Surface

Fig.1.5: Pulley shaft and its fracture Surface

Fig. 1.6: Armature Shaft of Locomotive and its fracture Surface

These photographs show failed components and their fracture surfaces. Most common feature in all these failures that can be observed in fracture surfaces is presence of ratchet marks on the shafts periphery, smooth fracture surfaces (wherever visible) indicating fatigue mode of failure.

IV. Macro and Micro features of failed components

Of these six failures, representative macro and / or micro structures are shown in Fig 2.1 to 2.4. The shafts were cut in transverse direction, machined and the cross section was then macro-etched with 50% HCL solution in water. The cross section macrostructure shows distinct weld region across the periphery of the shafts. Transverse metallographic samples were cut for observing microstructure. The general views of such mounted micro-samples are shown in Fig 2.2. In unetched condition, micro-cracks were revealed in the apparently weld region in most of these cases.

These samples were then etched with 3-5% Nital solution and observed under microscope. The etched microstructure in all these cases shows weld region at the surface (Fig. 2.3), heat affected zone (HAZ) and base metal. The base microstructure shows ferrite-pearlite microstructure for 45C8 and 55C8 materials. Base microstructure for 42CrMo4 and En24 shafts is tempered martensite and in some cases tempered martensite with bainite. HAZ in all cases is found to be majorly untempered martensite. Micro cracks are also visible in weld regime.

Fig. 2.1: Macro-etched surfaces of (a) Armature Shaft (b) Rotor shaft of impactor.

Fig. 2.2: Mounted micro samples of shafts showing distinct regions.

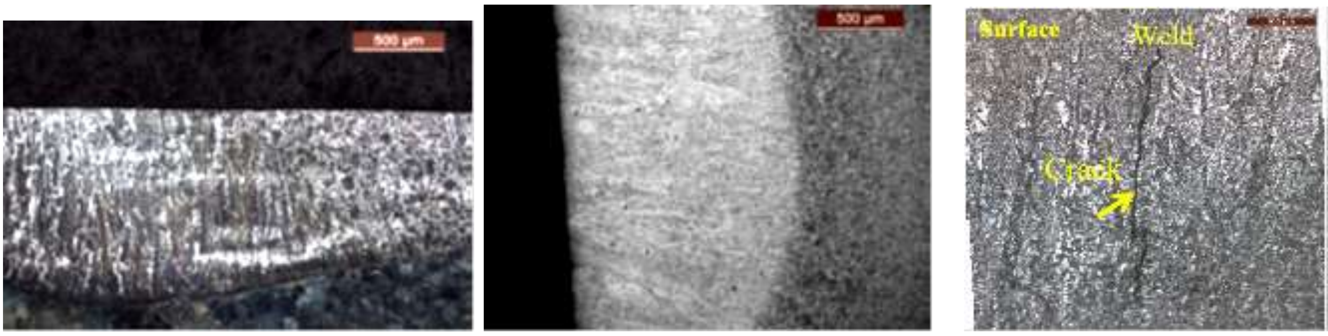

Fig. 2.3: Representative micro-structures of the shafts showing typical weld structure at the surface.

Fig. 2.4: Microstructures of one of the shaft showing transition from weld to HAZ to matrix

V. HARDNESS OF THE MATERIAL

Table 2: Hardness values of the shaft material in the various regions of microstructures

Sr. No.	Description	Weld	HAZ	Matrix	Unit
1	Shaft of Bend pulley	282, 285	***436, 434***	290, 302	HV 1
2	Rotor shaft of impactor	--	--	252, 256	HV 30
3	Squeeze roll shaft	180, 185	***230, 245***	188-192	HV 5
4	Support roll shaft	233, 230	***412, 410***	228, 230	HV 10
5	Pulley shaft at sinter plant	165, 167	***349, 351***	218, 221	HV 10
6	Armature shaft of Loco.	314, 317	***566, 560***	355, 357	HV 0.5

Hardness values of the shaft material in the various regions of microstructures (zones of weld) are compiled in table 2. It is evident that the hardness of HAZ is significantly higher than the weld and base metal causing incoherency across the microstructure. This leads to brittleness of the region which in turn leads to micro-crack initiation and reduced fatigue resistance. These micro cracks provide site of initiation for fatigue cracks during service [1].

VI. DISCUSSION

Welding processes has revolutionized the engineering applications. For this to happen, very high reliability of these joints is required. Reliability of any weld mainly depends on weldability of the material being welded, welding technique, welding procedure being followed and qualification of the welder carrying out the process. One major benefit of welding is its ease of use in depositing metal on any surface; but this benefit is put to misuse by ill-informed workmen for repairing machining errors while salvaging the deformed components and similar other purposes.

This salvaging of shafts causes reduction of fatigue strength due to various reasons.[3]

i. Tensile strength of the weld metal is lower than the parent metal in most of the cases. This partly causes reduced fatigue strength. This layer is on the surface which is subjected to higher tensile stress during service than the core of shafts.

ii. Welding also causes generation of the residual stresses in the components: tensile in weld deposit and compressive in base metal, pertaining to the rigidity of the shaft. During service, these stresses add up with service stresses, thus, reducing fatigue life.

iii. Medium carbon or low alloy steels have higher carbon equivalent leading to higher hardenability. This reflects during welding in heat affected zones causing hardening and cracking in the region leading to reduction in fatigue strength.

iv. Along with these, inherent welding defects like porosity, slag inclusions, lack of fusion and cracks during the process also add up in reducing fatigue life of the components.

VII. CONCLUSION

All these failure analyses lead to only one logical conclusion, that, the salvaging, restoration or reclamation of components by welding should not be undertaken without due consideration of the various factors and consequences. Such components are often subjected to dynamic loading conditions during service. Such shafts or incorrectly salvaged machined parts can lead to failure of the components or in some cases total damage to the machine where they are fitted.

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