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Fracture analysis and embrittlement phenomena of machined brass components

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Abstract

Fracture analysis and metallographic characterization is performed in selected machinable brass components, for use in hydraulic installations. Evidence of brittle fracture was mainly indicated by the presence of intergranular failure and limited plasticity areas. Multiple cracking was observed at the most highly stressed areas, such as the crests of the threads, the cross section transitions and thinnest wall locations. Fractographic analysis performed using Field Emission SEM, suggested the occurrence of embrittling phenomena, probably attributed to overheating and subsequent Pb-phase grain boundary segregation. Metallographic cross section investigation rather supported the failure hypothesis, implying that hot shortness is the plausible cause of ductility trough and brittle failure.

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Keywords: Hot shortness; brass failures; failure analysis; fractography

1. Introduction

Leaded brass rods are widely used in a great variety of applications varying from decoration and architecture to electrical and mechanical engineering applications. Such special components, e.g. screws, nuts, bolts, fittings, connectors are produced mainly by automatic machining processes, starting from extruded and drawn brass rods. Hydraulic components, such as faucets and complex systems - connecting pipes (distributors, valves, adaptors) are fabricated via casting or stamping followed by machining and surface treatment. Brass rods are used as raw materials

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for the manufacturing of such final/end-use components, see Pantazopoulos (2002). The chemical composition of these alloys and especially their lead content (approximate Pb-content range: 2-3% wt.) provides high machining efficiency in high-speed and high-precision machining processes, since Pb serves as a chip-breaking constituent resulting in exceptional surface finish with the minimum possible tool wear due also to the reduction of the imposed cutting forces. The major in-process and in-service failures and their causes of the brass rods and the corresponding fabricated components, together with their typical microstructure and mechanical properties were presented by Pantazopoulos (2003), Pantazopoulos and Toulfatzis (2012) and in a case study by Pantazopoulos and Toulfatzis (2013). Characteristic studies pertaining to the machinability and cutting performance of leaded brass rods and the influence of present phases (α+β), together with Pb particle size and distribution, have been elaborated by Pantazopoulos (2002), Toulfatzis et al. (2011) and Garcia et al. (2010).

Hot shortness, resulted mainly from chemical segregation of low-melting point constituents, such as Pb, occurred at high temperatures during the extrusion process as a result of combination of high extrusion speed and/or temperature, see Pantazopoulos and Vazdirvanidis (2008). Momentary sticking at the die land is also another possible failure reason inducing surface cracking, see Dieter (1988). The concentration of minor alloying elements to the interface and grain boundaries is considered as an embrittlement factor, especially at the temperature range between 300 and 600^0C, see Laporte and Mortensen (2009). In the embrittlement temperature range, the diffusion of Pb could lower grain boundary and interface surface energy, promoting intergranular cracking, see Wolley and Fox (1988).

In the present study, characteristic failures of leaded brass machined components, principally used as fittings in hydraulic installations were presented and their fracture mechanisms and plausible cause(s) are documented and discussed. Visual examination, optical microscopy and SEM analysis were used as the principal analytical techniques in the context of the present failure analysis investigation.

2. Experimental

Chemical analysis, whenever required, was performed using optical emission spectrometry and electrolysis. Macroscopic observations were by carried out by a digital camera and also using a Nikon SMZ 1500 stereomicroscope. Microstructural and morphological characterization was conducted in polished sections and the cross-sections were prepared via water grinding using successive abrasive SiC papers up to 1200 grit, followed by fine polishing using diamond and silica suspensions respectively. Rinsing in alcohol and drying in hot air stream were used as finishing procedures. To reveal the microstructure, immersion etching was performed using $FeCl_3$ based solution. Metallographic studies were performed using a Nikon Epiphot 300 inverted optical microscope while higher magnification observations of microstructure and fracture surface topography were fulfilled using a FEI SFEG XL40 SEM (using SE and BSE imaging modes).

3. Results and discussion

3.1. Hexagonal fittings fracture

Two machined components manufactured from hexagonal 27 mm, across flats, CW614N brass rods, exhibiting axial cracks were submitted for failure analysis investigation (Fig. 1a). The overall chemical composition analysis conducted by Optical Emission Spectroscopy is shown in Table 1.

The failure occurred via a macroscopically brittle fracture mode started from the surface of the rod, as shown by the radiating chevron marks (Fig. 1b).

Optical microscopy showed a rather brittle crack profile close to the surface of the original rod surface (Fig. 2), while the initial crack extended through a limited ductility fracture path caused by localized plastic deformation. Crack tip exhibited a rather blunt shape followed by brittle intergranular network as it was also confirmed by Scanning Electron Microscopy.