Characterization of the Microstructural Aspects of Machinable $\alpha$-$\beta$ Phase Brass

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**INTRODUCTION**

Machinable brass contains lead above 2% wt. However, lead contents ranging from 2.5 to 3.5% render the alloy exceptionally machining efficient which can be evaluated with the following criteria:
- Tool wear rate – expected/measured tool life (Taylor equation [1])
- Surface finish
- Machined work piece dimensional tolerances
- Cutting forces
- Machining chip size

Dual-phase brass microstructure comprises alpha ($\alpha$) and beta ($\beta$) phases. The alpha phase is a fcc solid solution, and the beta is the intermetallic non-stoichiometric CuZn compound having a bcc crystal structure.

The general production processes (casting and metal forming) along with a general machinability evaluation of the brass rods and the relevant standards have been presented [2, 3]. The major in-process and in-service conditions (and failures and their causes) of the brass rods and their related components have been reviewed [4].

**MATERIALS AND METHODS**

**Materials**

The composition of the examined material was checked by optical emission spectrometry and electrolysis and is presented in Table 1, where it is compared with the standard specification EN 12164:1998 [5].

**Specimen Preparation**

Microstructural and morphological characterization was conducted using mounted cross-sections made parallel and transverse to the extrusion direction. Grinding was performed...
using successive abrasive SiC papers, followed by fine polishing using diamond and silica suspensions, respectively. Rinsing in alcohol and drying in a hot air stream were used as finishing procedures. To reveal the phase structure, immersion etching was performed using ferric chloride solution made by dissolving 8.3 g FeCl$_3$ in 10 ml HCl and 90 ml H$_2$O.

**Light and Electron Microscopy**

Metallographic studies were performed using a Nikon Epiphot 300 light microscope. Samples were examined in brightfield and darkfield reflected light modes using 10× NA 0.3, 20× NA 0.46, 50× NA 0.8 and 100× NA 0.9 objectives. Images were taken with a Nikon Digital Net DN100 camera with 1.3 megapixels resolution and then processed using Image-Pro Plus image analysis software.

Scanning electron microscope observations of the fracture surface were conducted at 20kV with an FEI (Philips) XL40 Shottky field-emission gun scanning electron microscope equipped with secondary and backscattered electron detectors and an EDAX energy-dispersive X-ray spectroscopy (EDS) system for surface elemental analysis.

**Hardness Testing**

The material's temper was confirmed by employing hardness testing using an Instron-Wolpert NT1100 Vickers indentation device under 49.05 N applied load, according to EN ISO 6507 standard [6].

**CHARACTERIZATION OF BRASS MICROSTRUCTURE**

The microstructure of the as-cast brass billet is shown in Figure 1. The cast structure is characterized by a typical Widmanstätten morphology consisting of α-intersecting crystals in a β-phase matrix, which has resulted from solidifi-
cation processes during casting.

Brass bars of a wide range of diameters are fabricated by further metalworking by employing hot extrusion and cold drawing. The normal metallurgical condition corresponding to the high-machinability brass bars is that of the so-called half-hard temper (denoted as R430, see [5]). The brass bars which we examined had a nominal hardness up to 120 HV5 at the midway position (intermediate position between the periphery and the centre).

The dispersion of lead particles in extruded and drawn brass bars as seen in longitudinal and transverse sections is shown in Figures 2a and 2b while its distribution for both samples was evaluated through quantitative optical metallography using image analysis software. Enhanced contrast image processing was employed to sharpen the existing differences in Pb particle distribution (Figure 2c). The mean particle diameter calculated by image analysis was close to 1 µm. Uniformity in lead distribution is a function of population density which is expressed as the number of particles per surface area (mm$^2$). Machinability is improved by decreasing the lead particle diameter and increasing the population density for a given lead concentration.

The phase structure consisted of α-phase crystals precipitated in a β-phase matrix as shown in Figure 3. The β-phase had a higher contrast compared with the α-phase, as shown by means of brightfield illumination light microscopy (Figure 3a). The phase contrast was inverted under darkfield illumination (Figure 3b). A higher magnification brightfield micrograph showing the detail of the α-β microstructure is presented in Figure 3c.

The α/β interphase boundaries are high interfacial energy sites and, hence, potential lead distribution centres. Machinability is improved by increasing the size of the interphase boundaries, which is affected by the β-phase content and the size of the α-phase crystals. Higher β-phase volume fraction and finer α-crystals (for a constant α-phase content) tend to create longer interphase boundaries. The β-phase volume fraction measured by image analysis software was up to 35%.

Apart from chemical composition, the phase structure depends on the casting and thermo-mechanical process conditions, mainly casting speed, extrusion temperature and cooling rate. SEM studies revealed an α-β dual phase structure with a fine distribution of non-dissolved lead particles (Figure 4a). The characteristic EDS spectra of α and β phases are shown in Figures 4b and 4c. The presence of β-phase lowers the overall ductility of the material enhancing, therefore, the segmentation of machining chips.

Beta phase also exhibits a characteristic platelet-type morphology possessing different orientation among the various grains, as shown in Figures 5a-c. This layered type morphology demonstrated by β-phase could be considered beneficial for chip-breaking during machining.

Lead preferred concentration sites are mainly the α/β interphase boundaries. In addi-
tion, depending upon the casting and thermomechanical process parameters, lead is in a molten condition during metalworking, tending to take a spherical shape thereby reducing the surface energy. Furthermore, the lead droplets coalesce resulting in the formation of bigger lead islands, arranged at the α/β interfaces and minimizing the interfacial energy (Figure 6). The lead coalescence increases the mean particle diameter and decreases the population density, with an adverse effect on machinability.

**CONCLUSIONS**

In the present work the principal microstructural features of α-β high machinability brass are presented:

1. Lead is insoluble in brass at the solid state and forms ‘islands’ consisting of spherical particles occupying the α/β interfaces. The decrease of mean particle diameter and the increase of particle population density (for a given lead content) results in a substantial improvement in machinability.

2. The phase structure consists of α-phase crystals precipitated in a β-phase matrix. Beta phase exhibits a characteristic plate-type morphology, grown in different orientation directions among the various grains. The α/β interphase boundaries are high interfacial energy sites and, hence, potential lead distribution centres. The size of interphase boundaries plays a significant role in rod behaviour during machining and tends to be increased with the β-phase content and by reducing the size of α-phase crystals (for a constant α-phase content).

**REFERENCES**

5. EN 12164-1998: Copper and copper alloys: Rod for free machining purposes. European Committee for Standardization (CEN), Brussels, Belgium.

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<table>
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<tr>
<th>Sample / Standard</th>
<th>Cu</th>
<th>Zn</th>
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<th>Fe</th>
<th>Ni</th>
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<td>2.5-3.5</td>
<td>0.30 max</td>
<td>0.30 max</td>
<td>0.30 max</td>
<td>0.050 max</td>
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Table 1: Typical chemical composition of the brass bar sample (% wt.) *Confirmed by electrolysis.