Copper-Zinc-Lead Alloys, Common Defects Through Production Stages and Remedy Methods

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Abstract: Two types of leaded brass alloys (CuZn40Pb2 and CuZn39Pb3) as extruded rods, which use to produce pressurized gas valves were produced by a vertical semi-continuous casting, hot extrusion, cold drawing, hot forging and machining processes. The effect of lead element on machinability of these alloys was explained. The common defects of the mentioned leaded brass rods, the causes and its remedies were explained. Many defects during productions stages of leaded brass rods were occurred, such as cavities, non-metallic contaminates, lead clustering, surface cracks and zinc segregation into foundry process. In addition, surface crack, hot tearing and back defect through hot extrusion, chevron and chemical composition cracks into cold drawing with hot bursts and lap during hot forging were appeared. The machining process and in-service processes were also involved some other defects. All these defects were occurred due to no care during manufacturing process stages and using improper technological parameters and bad casting product design. To remedying the above-mentioned defects, the proper and improving technological parameters with optimal product design must be used. The current technical review of all types of defects in leaded brass alloys, have been found that, these defects can be appear and increasing in sub-sequence applications and in-service stages.

Keywords: Leaded Brass, Casting, Extrusion, Hot forging, Processing Defects

Introduction

Copper and its alloys, such as bronze, brass, are the materials which are widely used in friction parts of machines, as bearing liners, bushings, etc. Properties such as high strength and ductility, fatigue strength, wear resistance, etc. are necessary for these materials. Obtaining such properties is possible by creating sub-microcrystalline and nanocrystalline structures in the materials (Sadykov, 1999).

Principle of brass bars manufacture from the viewpoint of forming lies in the following technological scheme. Melted brass is poured into billets of circular cross-section with diameter (D). Brass billets are hot extruded to the required cross-section of a circle, square, hexagon and profile. After removal of surface oxides the brass extruded rods are cold drawn (calibrated) to the required dimension (PERNIS, 2011).

There are two broad categories of brass rods, as far as their end-use and final product fabrication technique, the forging/stamping rods and the machining rods. Machinable brasses are produced by hot extrusion and drawing and serve as raw material for the production of various products ranging from decoration to mechanical and electrical engineering. The production of the final parts is realized by high-speed machining (turning) of feed stock material, for maximum productivity, using automatic and CNC machining centers. Lead precipitated in a fine and homogeneous distribution, serves as a chip-breaking constituent, minimizing the friction at the tool/work piece interface and impairing the chip ductility, increasing, therefore, the machinability of the material and extending the cutting tool life (Toulfatzis, 2011). Lead (Pb) content and Pb particle dispersion played an important role in the machining capability of the material. Pb remained insoluble to the α or β phase and it was distributed along the present (or former) grain boundaries. As the Pb particle distribution became finer (less than 5 μm) and more homogeneous, the chip-breaking action during cutting processes became stronger, and therefore the machinability was enhanced (Pantazopoulos, 2002).

Leaded brass rods are widely used in applications varying from decoration and architecture to electrical/electronic and structural systems. Such components, for example, screws, nuts, bolts, and fittings, are produced mainly by automatic turning operations (Pantazopoulos, 2008). The content varies Pb between 2.5 and 3.5 %, which allows for machining processes at high speed with good surface (Mannheim, 2009). The solubility of lead in copper alloys is very low and for that reason it is found in microstructure as dispersed globules all over the material. It acts as a lubricant decreasing the friction coefficient between the tool and the material, creating discontinuities that promote the chip fragmentation, reducing the cutting force and the tool wear rate (Vilarinho, 2005). Different alloying elements enhancing the machinability are usually added to brass. The most important element in this context is lead, improving the machinability with regard to excellent chip breakage, low tool wear and high applicable cutting parameters. These aspects can be explained by two basic phenomena. First of all, solubility of lead in brass is very low and lead segregates in the entire microstructure, particularly at the grain boundaries. Hence, shear strength is significantly reduced, resulting in very good chip breakage. Secondly, lead exhibits a low melting temperature. During cutting, a thin, semi-fluid lead film reduces friction, cutting forces (Nobel,2014).

Materials and Methods

The methodology adopted to carry out this work involved wide studying of copper-zinc-lead alloys with two types (CuZn40Pb2 and CuZn39Pb3) as extruded rods which use to produce pressurized gas valves by hot forging, trimming and then machining process. The production sequences of leaded brass rods generally involves the manufacturing stages:- Vertical semi-continuous casting → Hot extrusion → Surface cleaning (pickling) → Cold drawing → Straightening → Stress relieving → Hot forging → Trimming & cleaning and Machining.

The study involved introduction about copper alloys especially leaded brass alloys and explain with discussion the common defects during production stages for two types of these alloys with its remedy methods. The study involved also some conclusions in finally.

The Common Defects of Leaded Brass Rods and It's Remedy

3.1 Foundry Process Defects

There are many types of defects appear into leaded brass billet casting such as:-

• **Surface defects: -** For certain products, such as those will have no machining after casting the surface finish is important and mould surface texture is reflected in that of the casting surface. For any blemishes or high and low spots will be carried over onto the product (Wilby, 2012). These defects can be avoided by adjust proper pouring temperature, repairing or replace the linear of casting mould and using oil lubricant for mould (Rajkolhe, 2014).

• **Zinc segregation: -** This can appear on the surface of billets in the case of insufficient the technological parameters and cooling of brass in chill-mould (PERNIS, 2011).

(Fig. 1) shows surface zinc segregates. These defects can be remedied by optimal casting parameters, repairing the cooling system of casting mould and adjusting the quality and cooling rate water.

• **Surface blackness cracks and lead clustering: -** The shortage and insufficient secondary cooling water lead to defects and surface cracks within the product. If the secondary cooling of the billet is not homogenous (non-uniform), this results the cracks, lead clustering and distortion of the billet (Hameed, 2014). **(Fig. 2)** shows lead clustering on brass rod surface. These defects can be avoided by controlling on technological casting parameters especially, cooling rate water and casting speed.

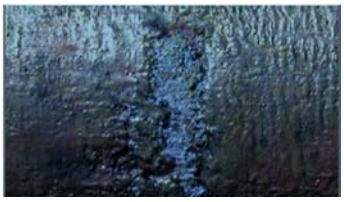

Fig. 1. Zinc segregates on brass CuZn40Pb2 billet (PERNIS, 2011).

Fig. 2. Lead clustering on leaded brass billet surface

•**Cavities and Porosity**: - These defects can be cause surface or internal cracks and/or voids that ultimately lead to failures during the metal forming operations. Careful selection of casting speed and cooling rate are viable techniques to control and minimize the solidification shrinkage and the associated porosity (Pantazopoulos, 2003). **(Fig. 3)** shows some porosity defects on section of leaded brass billet.

• **Non-metallic contamination: -** Slag or fragments of melting furnace refractory might be allowed to enter the melt charge during the pouring. Foreign attachments and extraneous materials get into billet where they become hard and follow into the extrusion process. The consequence of this is illustrated in **(Fig. 4)** (PERNIS, 2011). High, localized impurity levels may lead to cracks and discontinuities after extrusion and drawing. The necessary corrective action to avoid this set of defects is to establish the lowest possible impurity limits and to determine the chemical composition of the incoming raw material and/or the ingots from the casting process (Pantazopoulos, 2003). These defects can be remedied by pouring from the bottom of tundish and cleaning the molten metal from slag and dross (PERNIS, 2011).

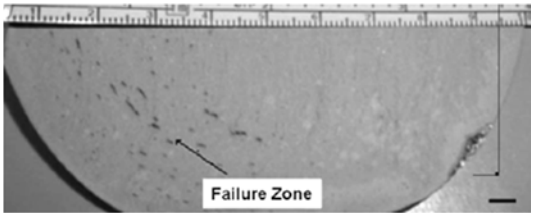

Fig. 3. Porosities and small cracks on brass billet (Mannheim, 2009). **Fig. 4.** Surface crack on extruded brass bar (PERNIS, 2011).

3.2 Extrusion defects

There are many types of defects occurring through extrusion process, but the common defects are:-

• **Surface cracks: -** The cracks may be small fine or transversal cracking, surface defects of brass bars are influenced by improper geometry of extrusion equipment. **(Fig. 5)** shows transversally deformed brass CuZn40Pb2 bar. This deformation was caused by the geometry of extrusion die which was manufactured with slightly twisted positions. If extrusion tools (die, the holder of die) is not sufficiently preheated up to required temperature, it can lead to the occurrence of cracks at the beginning of the extrusion process (PERNIS, 2011). The most important of technological parameters of extrusion processes; such as extrusion ratio, extrusion speed (ram speed), the temperature of extrusion and suitable preheating of forming tools extrusion ratio and extrusion speed effected to appear some surface defects especially, when extrusion ratio increase and the temperature of extrusion tools decrease (PERNIS, 2011).

• **Hot tearing or hot cracking: -** Hot-shortness failures appear as surface cracks or delaminations along the length of the extrusion. Hot shortness results from overheating because the temperature of the extrusion is increased by billet container friction. This increase in temperature raises the metal temperature to the point where localized regions of segregation may melt or become hot short (Rajkolhe, 2014). Surface/subsurface cracking and tearing with intergranular form can be generated by longitudinal tensile stresses developed as the extruded rod passes through the die. The most common reason is a combination of high extrusion speed or pre-extrusion rod temperature, while similar phenomenon could have occurred at lower temperatures due to stick-slip processes at the die land (Pantazopoulos, 2008). **(Fig. 6)** shows hot tearing defect on face of section for extruded lead brass rod which produced by Al-Shaheed state company, Iraq\Anbar. Although hot tearing is most often considered as a phenomenon linked to the inadequate compensation of solidification shrinkage by melt flow in the presence of thermal stress, there are more factors that could be involved in the formation of cracks at super solidus temperature (Mannheim, 2009). The factors that affect the hot tearing defects are a very high extrusion temperature, low extrusion ratio and a very low extrusion ram speed. To avoid this effect and prevent hot tearing the temperature of billet could be lowered and the extrusion ram increased (Mannheim, 2009).

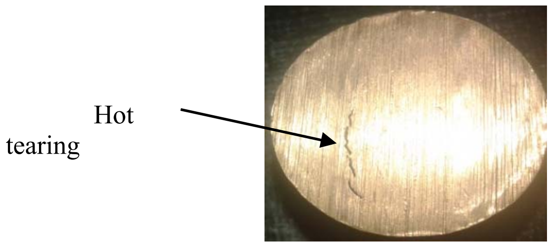

Fig. 5. Distortion of extruded hexagonal bar from brass CuZn40Pb2 (PERNIS, 2011). **Fig. 6**. Hot tearing in extruded brass rod

• **Back defect (internal piping): -** Which generally appears as a hole at the end of the extruded rod, results from a combination of the metal flow pattern and the introduction of surface oxides into the interior of the rod. Increased billet-container friction, an effect that frequently occurs in direct extrusion processes, gives rise to a non-uniform metal flow pattern, which is the main cause of the internal pipe formation (back defect) (Rajkolhe, 2014). In direct extrusion, if the extrusion ratio is too low, particularly with brass, the acceleration of the center of the billet can be so severe that cavities can occur toward the end of the section (**Fig. 7**), and due to the flow pattern of extrusion piping defects occurs (**Fig. 8)**. Their formation in the section can be prevented only by limiting the billet length and leaving a sufficiently long discard (Bauser, 2006). Removing a certain length form the end of the extruded rod can minimize the effects of this type of defect and the removing of the skin of the billet (scalping) during extrusion process also minimize this defect (Rajkolhe, 2014). In addition, the length of the billet is limited to reduce the risk of the piping defect. As a general rule the billet should not be longer than 2.5 to 3 times the diameter (Bauser, 2006).

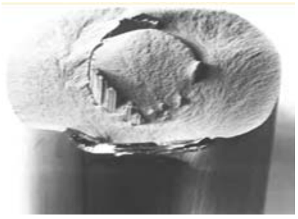

Fig. 7. Extrusion defect (piping) in leaded brass rod (Bauser, 2006). **Fig. 8.** End cavities in section of leaded brass rod (Bauser, 2006).

3.3 Cold Drawing Defects:

The types of defects associated with cold drawing failure of leaded brass rods include the following:-

• **Chevron or internal cracking: -** Chevron crack is a result of excessive die-material friction and/or too large a reduction in area during drawing. Appropriate die lubrication and controlling the rod reduction to between 10 and 15% may eliminate this defect (Rajkolhe, 2014). **(Fig. 9)** shows style of chevron crack appears in drawing rod.

• **Chemical composition defects: -** Melting charge for melting and casting of brass CuZn40Pb2 billets is made from the company's own material which bought from external sources. The company's own material has the ensured chemical composition. However, this can not be said about the material bought from external sources, where is always the risk of unsuitable impurities. The most dangerous impurity is antimony. Some standards allow antimony as impurity up to 0, 02 wt. %. Technological problems appear with cold drawing of such bars. The consequences of antimony presence in brass CuZn40Pb2 bars are demonstrated in **(Fig. 10**). It is a circular bar which was cold drawn and contained 0,018 wt. % Sb (Rajkolhe, 2014).

Fig. 9. Chevron crack defects in drawn rod (NORASETHASOPON, 2011). **Fig. 10.** Cracks on brass CuZn40Pb2 bar contains 0,018 wt. % of antimony (Rajkolhe, 2014).

3.4. Hot Forging Defects

The main types of hot forging/ stamping defects are:

• **Hot bursts:-**

• **Hot forging laps or discontinuities: -** The principal actions to minimize such these defects include (Rajkolhe, 2014):-

- First, and most importantly, review the processing stages and parameters with regard to the desired plastic deformation. These parameters include the alloy selected, the dimensions and geometry of the part produced, billet size, process temperature, strain rate, lubrication, die parameters, and other fabrication variables.
- Carefully adjust the preheating temperature. Excessive heating promotes hot tearing, and inadequate heating may lead to cracks due to insufficient ductility.
- Increase the alloy purity, and minimize alloy additions that may lead to hot shortness.
- Reduce friction through control of lubrication.
- Improve the die design to reduce sharp edges.

• **Surface cracking:** - Cause-Excessive working on the surface and too low temperature. Remedy by increase the work temperature (Rathi, 2014).

• **Cracking at the flash:** - This crack penetrates into the interior after flash is trimmed off. Cause due to very thin flash. Increasing flash thickness, relocating the flash to a less critical region of the forging, hot trimming and stress relieving (Rathi, 2014).

• **Cold shut (Fold):**- Two surfaces of metal fold against each other without welding completely. Cause due to sharp corner (less fillet), excessive chilling and high friction. Remedy by increase fillet radius on the die (Rathi, 2014).

3.5. Machining Defects:

When a good machining behaviour is required, lead is added (until 3%). The benefits conferred by the presence of lead has been appreciated for many years to facilitate chip fracture, reduce cutting forces, increase the machining rate and productivity, reduce tool wear and enhance surface finish (Garcia, 2010).

The chip shape obtained during machining is a very important factor of a material because it describes the possibility of using automatic machining processes. To do so it is necessary that the chip will be easy to remove and will not wind up on cutting tool what could influence the surface quality and tool life. To fulfill all these demands the chip has to be segmented. Lead is added to brasses and other copper alloys to force chip segmentation (Kondracki, 2003).

There are some defects and problems involved or appeared in machining process of leaded brass castings, such as hot crack propagation, lathe jaws marks and thin surface deflection of brass specimens as show in **(Fig. 11)** and **(Fig. 12)**.

Fig. 11. Hot crack propagation in machined leaded brass

Fig. 12. Jaws marking and cracks in lead brass

3.6. In-Service Defects

• **Environmentally induced failures: -** Such as fatigue, stress-corrosion cracking (SCC), and dezincification corrosion. These defects are generally a result of specific combinations of environmental and applied and/or residual stresses. To minimize the risk of SCC occurrence, a stress-relief annealing should be employed after the final manufacturing stage (Rajkolhe, 2014).
• **Cold-deformation failures or defects**: - Caused by the severe room temperature plastic deformation that may accompany component production. These failures are expected in cases where the alloy formability is exceeded during cold working. Better materials selection (chemical composition, temper) and process design are the main corrective actions to avoid such failures (Rajkolhe, 2014).
• **Hot-deformation failures or defects: -** These failures include hot bursts and laps, which can be prevented by limiting the intrinsic and extrinsic impurities and by careful control of process parameters (temperature, heating duration, billet dimensions, die design, and lubrication) (Rajkolhe, 2014).

Conclusions

• Several types of defects that occur in leaded brass rods during production process stages, especially through casting, hot extrusion, cold drawing and hot forging processes.
• Most of these defects occur due to improper technological parameters and product die designs adopted through the production processes.
• Some of these defects can be appear in last activities of production but, the causes of occurring are due to previous process.
• The proper and improving technological parameters can be used to remedy most of leaded brass rods defects. In addition, quality control and quality assurance practices must be used.

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