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INFLUENCE OF HIP SINTERING TECHNIQUE ON THE RELIABILITY OF THE MECHANICAL PROPERTIES OF BRASS-AN EXPERIMENTAL STUDY

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Abstract

The reliability of the mechanical properties of any product plays an important role in the longevity of the product to work properly under various working conditions. In the present study, the effect of preparing brass alloy on its mechanical properties was experimentally studied. Samples of brass (60% Cu-40% Zn) were prepared by hot iso-stating pressing (HIP) sintering method and some main mechanical tests were performed on them included porosity, density, hardness and compression tests. Results of these tests were compared with corresponding tests on commercial brass alloys produced by casting in order to show the effect of the method of preparing on their mechanical properties. There was a significant improvement in the hardness and strength of the sintered alloy due to the increasing in density and decreasing in porosity comparing with the corresponding other casting's alloys. Results showed an improvement in the density values by 8.4% as a result of the significant reduction in the porosity values from 8.65% to about 0.43%. As a result, the strength of the alloys prepared by the heat pressing method has jumped to a value of 600MPa compared to the traditional castings that have a strength of 343MPa.

Keywords: Reliability, hot isostating pressing, brass alloys, sintering, improving mechanical properties.

1. INTRODUCTION

The high relative strength and good corrosion resistance in addition to its high electrical and thermal conductivities, and economically costs made brass as one of the most important alloys required in industry [1-3]. Most of the industrial applications related to metal forming prefer alloys that are characterized by the plastic formability, and this is an additional feature that contributed to the spread of brass alloys in most industrial products [4-6]. As a result, many researches have been conducted with the aim of improving the mechanical properties of brass alloys either by adding alloying elements or by conducting special heat treatments.

The adding of lead as an additional alloying element is one of the most common ways to improve mechanical properties of brass due to its low cost [5,7]. The main reason for the improvement of the mechanical properties related to machining and formability when adding lead lies in two points: The first point is that the solubility of lead in copper is very low. This will lead to its accumulation on the grain boundaries of brass alloy, which facilitates its breaking during formation. The second point is that the melting point of lead is low, which greatly facilitates its melting due to the heat of friction during cutting operations [7]. This helps greatly in reducing the necessary cutting forces and increasing the life of the cutting tools, which are very important things in the cost calculations for any production process.

Unfortunately, the use of lead carries some health risks, so it is recommended to reduce the levels of lead in products drastically, as lead loses its ability to improve the properties of brass in current products. In addition, some applications related to the electronic industries require a high conductivity of the brass alloy, which will be somewhat negatively affected if lead is used as an additional alloying element. Therefore, many researches have directed towards finding a suitable alternative for lead to be added to the brass alloy, or finding new ways to improve the mechanical properties away from adding any additional alloying elements. On the other hands, many researches tried to investigate new production methods, despite the fact that any environmentally friendly production method is a great challenge in itself [8].

2. PRODUCING LEAD-FREE BRASS

The use of lead-free copper alloys has many disadvantages in terms of machining and cutting costs. Such alloys will reduce the life of the cutting tools due to the long shape of the pure brass grains. Many studies dealt with the possibility of using alternative elements such as selenium and bismuth instead of lead to enhance the machinability of lead-free brasses. Other researches dealt with the possibility of using graphite to improve the mechanical properties of lead-free brass [9,10]. Such attempts involve difficulties in preparing the alloy and relatively high costs, in addition to some rare elements that are freely present such as bismuth, so the use of these elements is not economically suitable for mass production processes. Boron is also one of the elements that can be used as an alloying element, but it will lead to the formation of hard areas within the alloy as a result of its chemical bonding with the iron element found in commercial brass alloys [11]. Therefore, research was directed towards the use of lead-free commercial brass alloys that have been available for more than twenty years [12], and attempt to improve their properties by heat treatments. All of those attempts were to make brass be in line with the current legislation that restricts and specifies the percentages of lead allowed to be present in any product.

Unfortunately, the use of the traditional casting methods produces coarse grains and heterogeneous within the microstructure of the products. This requires finding suitable methods for treating the molten liquid before it solidifies in order to ensure a more homogeneous microstructure [13]. However, this may lead to problems in thicker castings, especially when using additives that are resistant to heat conduction, such as sand or ceramics, for example. Therefore, in such cases, the appropriate timing of the addition should be taken into account during the solidification process. In addition, some additives are difficult to control as they will separate from the product in the form of slag and will not perform the role required of them [14].

One of the most important ways to improve the mechanical properties of bass is to refining grain sizes, and there are many methods used to achieve this, including the multi-pass conventional method [15, 16]. Ultrasound vibration is another method that has been investigated in many studies. Where it was found that the brass alloys untreated by ultrasonic vibration contain alpha-dendritic phase with an average length of 156 μm overlapping with a coarse beta phase. While brass treated with ultrasonic vibration showed a significant improvement in the alpha phase with an average length of 21 μm, which greatly improved the mechanical properties of the product [13].

In this study, brass was prepared using hot isostating pressing technique HIP. Tensile tests were conducted for the prepared alloy and results were compared with the brass standards to show the effect of the preparation method on the mechanical properties.

3. MATERIALS AND METHODS

3.1. Raw powders

The purity of powders plays a major role in the specification of products produced by powder metallurgical method [17]. Therefore, copper and zinc powders with a high purity of up to 99.9% were used, prepared by electrolysis method from Sky Spring Nanomaterials Inc. In addition, the closeness in the meshing size between the mixed powders contributes greatly to reducing the segregation during the preparation stages, leading to a more homogeneous alloy [18]. The size of the particles used was 44 microns as an average with meshing size of (-325). The mixing ratios of the powders were 60% copper and 40% zinc for the purpose of comparing the results with traditional brass with the same mixing ratios.

A suitable vibrating mixing equipment shown in figure (1) was used to mix a quantity of powders with a rotation speed of 90 rpm and a mixing time of up to six hours.

Fig. 1. Vibrating rotating mixer equipment used in this study

3.2. Preparing capsules from mild steel

The HIP process is a sequential process that begins with the preparation of the pressure capsule and ends with the capsule being compressed into a convection oven under hydraulic or gas pressure (Fig. 2). According to that, a special capsule of mild steel must be prepared as a first step. Mild steel pipes of different diameters were used and welded as shown in figure 3 for the purpose of filling them later with the mixed copper and zinc powders.

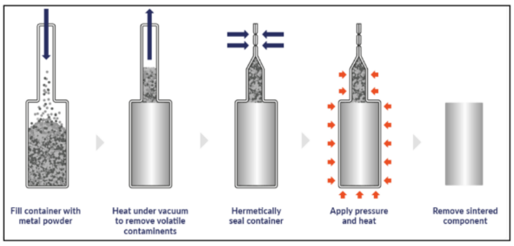

Fig. 2 The main steps of HIP sintering technique (Source: https://rightonblackburns.co.uk)

The welding process must be professional to ensure that there are no pores from which gases may escape from or to the capsule during the HIP process. Therefore, it is very necessary to check the tightness of the capsule's closure by using a special vacuum device for this purpose. The capsule was installed in the vacuum device as shown in figure 4. while a stream of helium gas was used and the vacuum pressure gauge was carefully noted during that. Helium gas is very light gas, so it will easily penetrate into the vacuumed capsule if there is any defect in the welding areas. After making sure that the vacuum gauge was not affected during the helium gas shed process, it was ascertained that the welding process of all the edges of the capsule was good.

Fig. 3. Welding HIP mild steel capsule

Fig. 4. Inspect the welded capsule to ensure that no gases leak from or into it

After confirming the tightness of the welding areas, the prepared capsule was filled with a mixture of the pre-prepared powders. Then degassing process was conducted using the special degassing accessories shown in figure 5. It is preferred that degassing takes place under heating to moderate temperatures to remove volatile contaminants from the mixture. This process must be a slow for several hours so that the powders do not leak out of the capsule during degassing.

At the end of degassing and while the capsule was still under degassing equipment, the hydraulic press arm shown in figure 6. was used to seal the capsules filling tube. Thus, the capsule filled with powders became ready for HIP process.

Fig. 5. The degassing equipment

Fig. 6. Seal the capsule using a hydraulic press

3.3. HIP sintering

Hot isostating pressing technology is one of the techniques that greatly helps in squeezing the pores within the structure of the final product and this will greatly improve the mechanical properties [19]. In this technique the powders will be insured from oxidation due to the absence of oxygen during the sintering stages. The continuous pressing and heating at the same time lead to produce high-density products with high static strength. In addition, no segregation or grain growth can take place during manufacture and this also improves the fatigue and mechanical wear resistance. The HIP equipment used in this study is shown in figure 7. A pressure of 150 MPa was supplied with heating up to 800 ° C for two hours with heating rate of 10°C per minute, while cooling was carried out using an air jet at the end of sintering process.

After completing the HIP process, the capsule was extracted from the furnace, which will certainly have a smaller size than the initial size before sintering due to pressure and heating. Wire cutting method was used for the purpose of cutting samples and preparing them later for the different mechanical tests that were carried out in this study as shown in figure 8.

Fig. 7. The HIP sintering furnace

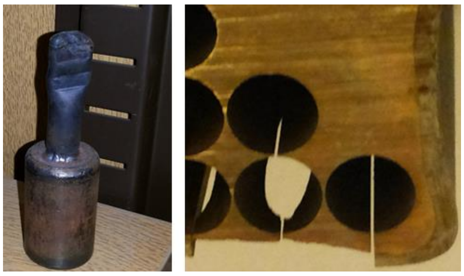

Fig. 8. Preparing samples by wire cutting

3.4. Hardness and compression tests

In this study, hardness test was carried out to check the ability of withstanding plastic penetration of the final product. Hardness of samples prepared by HIP sintering technique was compared later with the corresponding hardness of traditional brass. The hardness device used in this study was of type Avery-6402-100kgf direct Rockwell reading hardness test machine as shown in figure 9.

Fig. 9. Avery Rockwell device

Universal test machine of type (HTM-200 KN) was used to compare the compressive strength of the prepared samples with the known values of commercial grades brass. The test was carried out according to the standard (ASTM - A1990) [20], where the test sample was cylindrical, with a diameter of 30 mm and a height of 25 mm (Figure 10). Experiments were conducted on three samples and the average readings were taken for the purpose of comparison later.

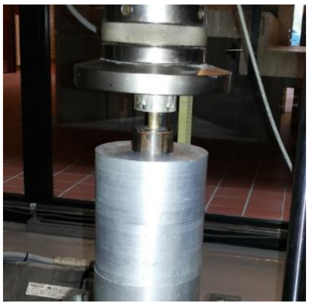

Fig. 10. Samples during compression test

3.5. Density and microstructure analyses

It is very important to observe the microstructure of the prepared samples using the microscope to note the improvement in their porosity. Therefore, small samples were cut using a laboratory saw and grinding operations were performed on them in a gradual manner using grinding papers starting from 400 to 2000 grades. Polishing was carried out using a solution of alumina and distilled water.

On the other hand, density of the prepared samples was measured using the device shown in figure 11, which works mainly according to Archimedes' rule.

Fig. 11. Density measuring device according to Archimedes principle

4. RESULTS AND DISCUSSION

4.1. Results related to density and porosity

Results of the density test showed that the products prepared by HIP have a higher density than those prepared by casting. The density of the HIP samples was (8.81 g/cm3) compared with a lower value for the density of the casting samples which was (8.13 g/cm3). This difference in the two values is a good improvement that will positively affect the mechanical properties. The main reason for this improvement in the density values is due to the porosity difference resulting from the difference in the preparation methods of the two tested samples. Figure 12, represents the microscopic examination of the surface of the prepared samples, the porosity difference between them can be observed. The percentage of porosity of the traditional casting samples was (8.65%) compared with a lower value for the porosity of the samples prepared by HIP method, which was within (0.43%).

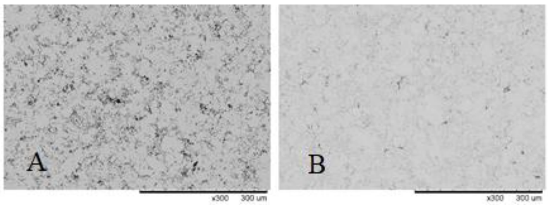

Fig. 12. Microscopic evaluation: (A) Traditional castings sample, and (B) Prepared HIP's sample

Porosity creates by two main reasons; shrinkage during solidification and gas porosity. Shrinkage is a widespread problem in nearly all type of castings. Contraction will take place during solidification and the remaining liquid will lose its ability to feed the loss of volume and defects as porous will appear.

On the other hand, there is relative gap between the melting point of zinc and copper and hence, some quantity of zinc will evaporate during casting and will lead to gas pockets within the final casting. Such gas pockets represent another widespread reason of porosity. Also, Atmospheric humidity which may mixed with molten metals will also cause some additional pores within the final product. Finally, and in addition, air may have trapped inside moulds during castings and represent an additional reason of porosity.

Most of the reasons mentioned above can be eliminated by HIP technique. As the continuous pressing during the heating and cooling processes will lead to squeezing the melted materials and compensating for shrinkage, thus eliminating the most important causes of porosity. On the other hand, complete isolation from external environment conditions along with the degassing process before sealing the powder capsule will eliminate the influence of atmospheric humidity during sintering. In addition, the continuous pressing will lead to a high interlocking between powders and reduce the phenomenon of zinc cavitation, which has a great effect in reducing the porosity.

4.2. results related to hardness and strengths

Results of the hardness test showed a significant improvement in the hardness of the sintered products by the HIP's method. The average of three readings of hardness measured for HIP's samples was (88.4HRB) compared with the hardness value of the traditional brass samples, which was within (74.5HRB). This is mainly due to the high density and low porosity values of the HIP's products.

On the other hand, the compression test showed a significant improvement in the values of the ultimate strength for the HIP's samples comparing with the corresponding values for the traditional casting's samples. The ultimate strength for the casting's samples were about 343 MPa as an average for three tests, comparing with the high result achieved by the HIP's samples which was just over 600 MPa. The same thing of improvement was obtained by the strain of both samples, where HIP's samples achieved strain values of about 47% comparing with the strain of the casting's samples, which would not exceed 35% as can be noted through (Figures 13 and 14).

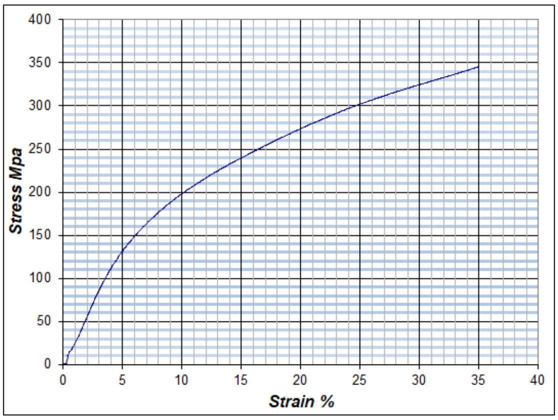

Fig. 13. Compression test result for traditional casting's samples

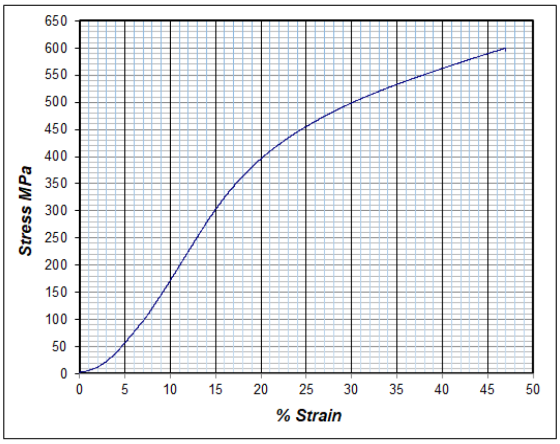

Fig. 14. Compression test result for HIP's samples

There are several reasons for which HIP's samples have gained this superiority in mechanical properties. The most important of these reasons is the low porosity values of the HIP's samples, which makes the micro-bonds better with each other. In addition, pores represent a micro-crack and would contribute to the failure of products due crack propagations according to Griffith's theory. Therefore, it is expected that localized plasticity will spread within the surrounding elastic region. Of course, crack propagation will lead to create new localized plastic region and propagate again due to the stress concentration factor around the sharp edges of pores. This phenomenon contributes greatly to the failure rate of samples of high porosity compared to those with lower porosity. In addition, the pores in the structure of the HIP's samples were much less in size than the pores in the traditional samples, as is clearly previously shown in Fig. 12. Such pores may not exceed the crack propagations' threshold that relates to crack lengths.

The other main reason is that the cast samples usually suffer from the phenomenon of evaporation of part of the zinc before it bonds with copper. This important defect will lead to form weak areas of semi-pure copper, which will certainly reduce the ability of the samples to withstand external stresses and reduce their ductility. In addition, the evaporation of part of zinc will lead to a decrease its percentage content inside the alloy and increase the percentage content of copper, and this will also reduce the mechanical properties of the final product.

5. CONCLUSIONS

An experimental investigation has been made of the effects of preparation methods on mechanical properties of products. Some concluding observations from this investigation are given below:

1. The method of preparing plays a big role in the mechanical properties of the final product. Therefore, it is necessary to choose the optimal method of preparation before conducting any study to improve its parameters.
2. Alloys prepared by the heat pressing method have a strength nearly twice that of alloys prepared by the traditional casting method.
3. The ductility of alloys prepared by heat pressing improves compared to their commercial counterparts by more than 34%.
4. Porosity decreases dramatically when using HIP's sintering method in preparing the products, as more than 95% of the pores can be eliminated using this technique. Low porosity ratios will certainly lead to an increase in the density of the material.
5. Choosing the HIP sintering method leads to a clear increase in the hardness of the products compared to their counterparts prepared by casting.

Declaration of competing interest: *The author declares no conflict of interest.*

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