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Study on the Effect of Production Parameters and Raw Materials Used on the Mechanical Properties of Leaded Brass (CuZn40Pb2) Alloy

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Abstract

Leaded brass alloys used progressively in many applications such as gas valves production owing to their excellent machinability, corrosion resistance and some other specifications. However, the production processes of these alloys involve some problems appearing in the last activities of production as a result of cumulative defects of previous production processes. Therefore, the current investigation studies the effect of process parameters during casting, hot extrusion and cold drawing production stages of CuZn40Pb2 leaded brass alloy on the mechanical properties. Starting with casting process, two types of charges were used. The first charge consists of 100% recycles while the second contains 30% of pure materials such as Cu, Zn and Pb in addition to the recycles. For each production stage, alloy hardness, micro-hardness, ultimate tensile strength and elongation were examined. The results illustrated that high hardness values are obtained during casting process due to some impurities such as iron and the effect of cooling rate through solidification. The hardness values decrease during extrusion process and then rise again by cold drawing for the charge of 30% pure materials. Micro-hardness values for the fractured tensile test samples appeared higher than others due to work hardening effect. The best mechanical properties as ultimate tensile strength of CuZn40Pb2 alloy products are appeared into cold forming samples with the 30% pure material added.

Keywords

Leaded Brass Alloy, Mechanical Properties, Hardness, Work Hardening

1. Introduction

Brasses with 58% or 59% of Cu in addition to some extent of lead are suitable for metal strips, bands, and bars production. At higher temperatures, it is possible to apply forging and pressing to these brasses. These alloys are difficult to cold form, while they can be forged [1]. Brass in the α-β range (free machining brass) has excellent hot workability [2]. To improve the required characteristics of brass alloys, some alloying elements are added. For example, copper machinability can be improved by adding lead, sulfur, tellurium and zinc. Lead in brass alloys with concentrations around 2 wt% improves machinability by acting as a microscopic chip breaker and tool lubricant, while they increase the brittleness of the alloy [3]. On the contrary, adding alloying elements such as tin and iron affect negatively to the brass machinability [4].

Machinable brasses are manufactured by hot extrusion and cold drawing, and serve as raw materials for the production of a broad range of products, such as bolts, nuts, electrical connectors, valve bodies, and hydraulic fittings. Moreover, leaded brass rods are widely used in applications varying from decoration and architecture to electrical/electronic and structural systems. The production of the final components involves various machining operations, such as drilling, milling, and turning [5] [6].

The strength and formability of extruded brass rods are strongly affected by the hot extrusion parameters which determine the grain sizes and the textures of extruded products. Additionally, in the case of CuZn40Pb2, multiple phase transformations arise during the hot extrusion process and affect the resulting properties [7]. Many technological parameters and forming tools have an influence on the hot extrusion process of brass. The most important technological parameters of the extrusion process include: the speed of extrusion, extrusion ratio, average shear strain rate, the temperature of extrusion and the suitable preheating of forming tools. Manufacturing experience with hot extrusion process shows that alpha and beta leaded brasses (CuZn40Pb2) are perfectly suitable for the extrusion process [8]. The material microstructure is highly affected by the production processes parameters and usually influences the properties of the material since any variation in microstructure can significantly change the strength, toughness, hardness, ductility and even thermal and electrical properties [9].

Therefore, the current investigation aims to study the effect of production parameters and the alloy constituents of raw materials on the mechanical properties of leaded brass (CuZn40Pb2) alloy which are used in gas valves production. Two brass alloys charges are considered; *i.e.* charge contains 30% of pure materials in addition to the recycled materials while the other is totally consisted of recycled materials.

2. Materials and Methods

The methodology used to carry out this work involves studying of leaded brass (CuZn40Pb2) alloy as casted billets, extruded rods and cold drawn rods. Leaded brass alloy (CuZn40Pb2) which consist of copper, zinc and lead is selected according to European Standards (EN), CW617N as shown in **Table 1**, to produce the castings required for the experimental work.

3. Material Preparation

3.1. Melting and Casting Processes

Melting and casting processes of CuZn40Pb2 alloy carried out with two types of casting alloys depending on charge materials and the casting parameters. The first alloy produced by using 100% recycles as charge materials. CuZn40Pb2 alloy recycle of gas valves for about 3000 kg are sequentially charged into coreless induction furnace. The melting point of the alloy mixture is located between 875 and 890˚C according to equilibrium diagram of copper-zinc alloy [11]. Temperature of molten alloy increased to 1050˚C and then chemical composition of alloy is estimated. The molten alloy temperature increased again to 1100˚C as pouring temperature before pour the melt into casting mold of a vertical semi-continuous casting machine. The molten alloy in casting mold covered with powder flux called "Cuprit 103" which is a white powder used as a protective cover on molten metal during the casting process. This protective cover will prevent any contaminations and will produce oil lubricant for mold liner after melt by molten metal [12]. The casting parameters used for this alloy are illustrated in **Table 2** which adopted according to the technical knowhow of the supplying company.

The second alloy produced by using 70% recycles in addition to 30% of pure materials such as Cu, Zn and Pb added as charge materials. The production process for the second CuZn40Pb2 casting alloy is performed by repeating the same production processes adopted for the first alloy except some changes adopted in casting parameters as illustrates in **Table 2**. The final products of

Table 1. Chemical composition of CuZn40Pb2 alloy according to EN standards [10].

Element %	Cu	Zn	Sn	Al	Pb	Ni	Si	Fe	Others
Max.	59	Rem.	0.3	0.05	2.5	0.3	---	0.3	0.2
Min.	57				1.6				

Table 2. Casting parameters of the two CuZn40Pb2 alloys.

	Alloy Batch No.	1	2
	Charge material	100% recycle (used gas valves)	30% pure materials + 70% recycle
Casting Parameters Limits	Pouring Temperature (˚C)	1050 - 1100	1000 - 1050
	Casting Speed (mm/min.)	200	180
	Vibration of casting mold (cycle/min.)	80 - 100	80-100
	Primary cooling water (m^3/hr.)	5	4
	Secondary cooling water (m^3/hr.)	3	3
	Inlet cooling water temperature (˚C)	25 - 30	25 - 30

casting processes are two strands of leaded brass alloy billets of 180 mm diameter and 6000 mm length.

3.2. Extrusion and Cold Drawing Processes

Samples of 180 mm diameter and 300 mm length prepared from the previously produced castings billets of the two alloys types. These samples are heated by induction furnace before extruded. Extrusion process carried out experimentally under two different extrusion conditions cases Table 3, to produce two extruded leaded brass rods of 32.2 ± 0.2 mm diameter in each extrusion action. The extruded rods after pickling and oxidation removing are cold drawn by hydraulic draw bench to produce (Ø 30 ± 0.1) mm diameter of straight leaded brass rods.

4. Mechanical Testing and Inspections

Numerous types of experimental inspection and test processes are carried out to acquire the mechanical properties of proposed CuZn40Pb2 alloys for pressurized gas valves production. Samples are collected from each stage of production processes (*i.e.* casting, extrusion and cold drawing). These samples are named and described depending on charge materials, location within the billet and production conditions adapted as illustrated in Table 4. After that, tensile, hardness and micro-hardness tests are carried out. In addition, some specimens are taken from the tensile test samples after their fracture to check the micro-hardness.

4.1. Hardness Test

The above mentioned fourteen samples (see Table 4) collected after casting, hot extrusion and cold drawing production processes under different conditions are grinded and polished carefully. A programmable hardness device (AFFRI 251 VRSD) is used to check and calculate the hardness of samples. Brinell hardness measured for each sample using 5 mm diameter ball indenter and an applied load of 62.5 N. The indenter mark pictures and diameters are calculated by optical lenses which equipped with hardness device, and then the hardness values are estimated and displayed onto the device screen. For each sample, three hardness measurements are taken and averaged to reflect its hardness value.

4.2. Tensile and Elongation Test

The tensile tests are accomplished for hot extruded and cold drawn rods sam-

Table 3. Hot extrusion conditions of CuZn40Pb2 alloys.

Type of Parameters	Case 1	Case 2
Preheating temperature of extrusion billet	700˚C	650˚C
Preheating temperature of extrusion dies	400˚C - 450˚C	400˚C - 450˚C
Extrusion speed	27 mm\sec.	30 mm\sec.
Extrusion ratio	17	17

Table 4. Samples names and their descriptions.

Sample No.	Description			
	Process Type	Sample Location	Charge Material	Parameters Condition
1	Casting	Right side of billet	100% recycle	Before improvement
2	Casting	Center of billet	100% recycle	Before improvement
3	Casting	Left side of billet	100% recycle	Before improvement
4	Casting	Right side of billet	30% pure material + 70% recycle	After improvement
5	Casting	Center of billet	30% pure material + 70% recycle	After improvement
6	Casting	Left side of billet	30% pure material + 70% recycle	After improvement
7	Extrusion	---	100% recycle	Before improvement
8	Extrusion	---	100% recycle	After improvement
9	Extrusion	---	30% pure material + 70% recycle	Before improvement
10	Extrusion	---	30% pure material + 70% recycle	After improvement
11	Drawing	---	100% recycle	Before improvement
12	Drawing	---	100% recycle	After improvement
13	Drawing	---	30% pure material + 70% recycle	Before improvement
14	Drawing	---	30% pure material + 70% recycle	After improvement

ples. Standard tensile test samples are machined according to ASTM E8M [13] on turning machine (VDEST-AIRINE, DA 300 MASEHINE type), and then grinded with abrasive paper of grade 2000 µm. Tests carried out at Mechanics of Materials Laboratory-American University-Cairo-Egypt, using a programmable tensile test device (INSTRON 3382 type) which has a capacity of 100 KN. Two groups of tensile test specimens are considered. The first group contains four specimens of 9 mm gage diameter while the other consists of four specimens with 6 mm gage diameter. The ultimate tensile strength and elongation of samples measured and the stress-strain curves are obtained.

4.3. Micro-Hardness Test

This test is performed only for the eight specimens obtained from the extruded (specimens 7 to 10) and cold drawn (specimens 11 to 14) processes after their fracture under the tensile test process. The micro-hardness values for the samples are checked using testing device LECO CORPERATION type, model 251 VRSD, 115\230 Volt. The load used is (100) gf and 10 seconds as dwell time. The test locations are selected on the surface and center of samples to explain the difference of hardness values between these locations. Three points of test values for each location on the sample are measured and then, the averages of these hardness values are estimated.

5. Results and Discussions

The results of this study include some mechanical test and inspection processes such as Brinell hardness (HB), micro-hardness (HV), ultimate tensile strength and elongation test results. These mechanical tests and inspection results will be illustrated and discussed in the subsequent paragraphs.

5.1. Hardness and Micro-Hardness Test Results

Table 5 presents the Brinell (HB) and Vickers (HV) hardness results for the collected specimens at different production stages. Noting that, Vickers hardness (HV) values obtained from Brinell hardness (HB) values according to ASTM E140-02 [14]. Moreover, Figure 1 shows the hardness values of all tested speci-

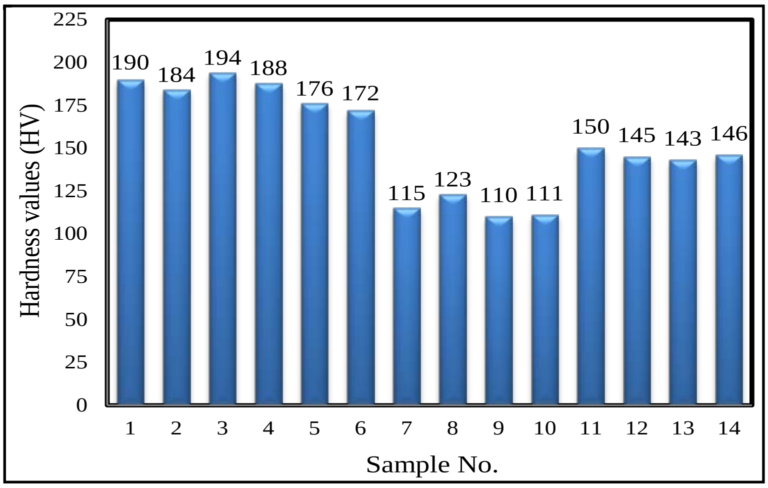

Figure 1. Hardness values of the tested samples.

Table 5. Results of mechanical tests carried on the different specimens of CuZn40Pb2 alloys.

Process Type	Sample No.	Hardness (HB)	Hardness (Vickers)	Micro-Hardness (Vickers) after fracture by tensile test		Ultimate tensile strength (MPa)	Elongation %
				Center	Surface		
Casting Process	1	163.5	190	---	---	---	---
	2	159.5	184	---	---	---	---
	3	166.7	194	---	---	---	---
	4	157.6	188	---	---	---	---
	5	151.4	176	---	---	---	---
	6	149.4	172	---	---	---	---
Hot Extrusion Process	7	100.2	115	170.3	163	402	20.9
	8	100.9	123	181.3	170.33	459	15
	9	97.2	110	155	150.6	404	24.3
	10	97.7	111	168	153.33	372	33
Cold Drawing Process	11	131.1	150	191.3	180	426	20.8
	12	127.3	145	198.3	180.3	434	22
	13	124.6	143	184.33	170.3	416	15.3
	14	127.8	146	190	182.33	452	20

mens which provide a rapid and complete comparison between the effect different production stages on the product hardness. These results explain that, the hardness of the first three specimens (*i.e.* 1, 2 and 3) which taken from casting process are more than other samples due to the effect of increasing in some impurities such as iron (Fe) and silicon (Si). The increase of these impurities leads to refine the grain size of these castings and therefore, increases the hardness values. Also, the microstructure of materials influences the properties of the material and variation in microstructure can significantly change the strength, toughness and hardness values [8]. The reasons of impurities rise are due to using the whole charge elements from brass valve recycles. Sample 3 has the highest hardness value compared to the other samples due to its location into the chill zone area of casting billet. The hardness values decreased in extrusion case as in samples 7 to10 due to the rise in temperature of billet castings during hot extrusion which leads to enlarge the sample structure. The hardness values are increased again during the cold drawing process due to the work hardening process and dislocation density increases which agree with the results of [15].

The micro-hardness test results of extruded and cold drawn samples after fracture by tensile test illustrate that, all hardness values are higher than other samples before tension due to the effect of work hardening. In same time, the hardness values are increased from extrusion to cold drawing processes due to the same reasons mentioned above. The maximum micro-hardness value (*i.e.* 198 HV, see **Table 5** and **Figure 2**) is appeared in sample 12 produced from 100% recycle and formed by cold drawing process. The comparison between the micro-hardness values in surface and center of tensile test samples (**Figure 2**) illustrate that, all hardness values in center are more than that in surface. The reasons for this difference can be explained by that the sample grain structures in center are small equiaxed grains, while the circumferential grains are larger due to the fact that the extrusion, drawing and may be torsion during tension makes the circumferential strain degree higher and microstructure finer. In addition, the work hardening of samples during tensile test process also contributed in these differences in micro-hardness values. These differences in hard

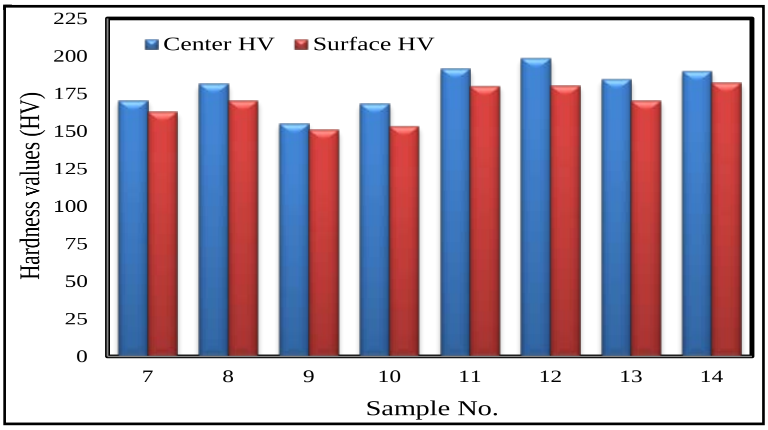

Figure 2. Center and circumferential micro-hardness results of the tested samples.

ness values between the center or circumferential hardness values and the radial or center hardness values supports also the results obtained by Li *et al.* [16]. Moreover, the differences in hardness results can be verified by microstructure observations.

5.2. Tensile and Elongation Test Results

Figure 3 and **Figure 4**) and also **Table 5** illustrate the results of ultimate tensile strength and elongation percent of extruded and cold drawn leaded brass samples. It can be noted that, the maximum ultimate tensile strength of 459 MPa is appeared for the 8th sample (**Figure 3**). The increasing in these values can be due to the strain hardening. In addition, this sample is already taken from the first alloy that produced from 100% recycle, which included some percentages of impurities as Fe and Si; therefore, the mechanical properties as tensile strength can be slightly increased which agree with the results of Jha *et al.* [17]. The best ultimate tensile strength is appeared by the14th sample due to using the mixture of pure materials and recycle into melting charge, and due to the cold drawing

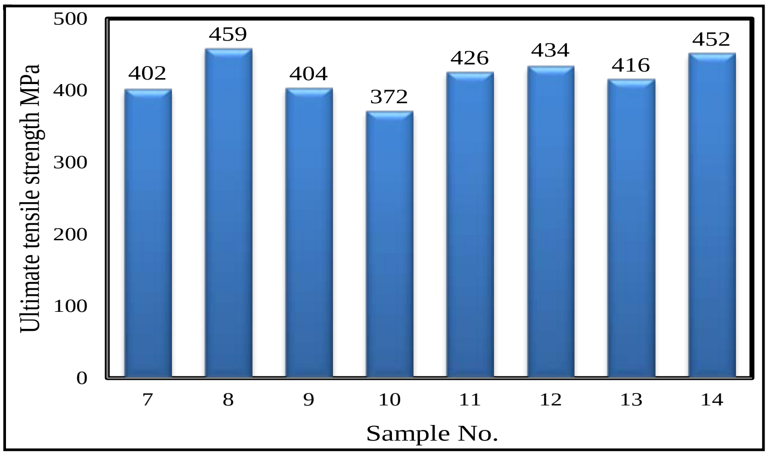

Figure 3. Ultimate tensile strength values of extruded and drawn leaded brass alloy specimens.

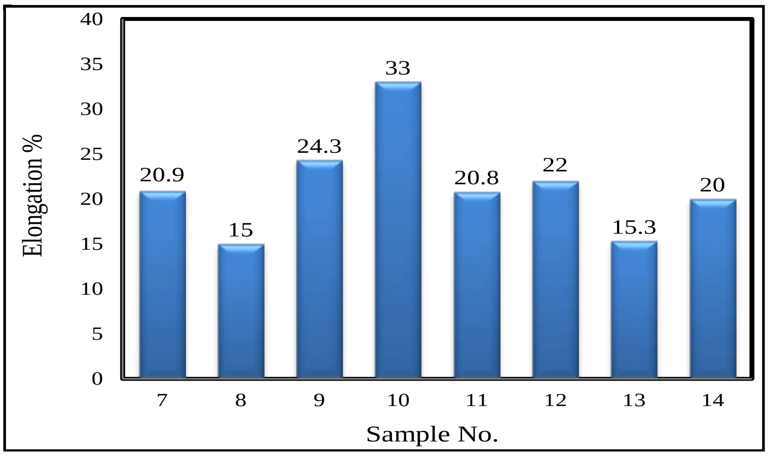

Figure 4. Percentage elongation values of extruded and drawn leaded brass alloy specimens.

process. The minimum value of tensile test is illustrated by the 10th sample, while the elongation appears of high limit in the same sample.

The elongation values for the extruded and cold drawn samples are affected by the initial charge and the parameters adopted for each stage in the production process. **Figure 4** shows the percentage elongation values of extruded and drawn leaded brass alloy specimens. It is worth to note that, the maximum elongation value appeared by the 10th sample which produced from an initial charge contains 30% pure material using casting process followed by hot extrusion process.

6. Conclusions

The effect of raw materials and process parameters during casting, hot extrusion and cold drawing production stages of CuZn40Pb2 leaded brass alloy used in gas valves production on the mechanical properties is investigated. The conclusions acquired from the current experimental investigation are as follows:

- Mechanical properties of CuZn40Pb2 alloy such as hardness and ultimate tensile strength are principally affected by raw materials and the production parameters used.
- Hardness values are high through casting stage and decreased after hot extrusion and finally increased after cold drawing.
- Best ultimate tensile strength appears when the mixture of pure materials and recycle is used into melting charge, and after the cold drawing process.
- More improvements in mechanical properties occur by cold forming with the addition of pure materials and some changes in production parameters such as billet preheat temperature and extrusion ram speed.

Micro-hardness values of fractured tensile test specimens of CuZn40Pb2 alloys are more than tested after casting, hot extrusion and cold drawing processes.

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