Differences in microstructure and tensile properties of brasses produced by Continuous casting and thermomechanical processing

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Abstract: - Microstructures of the components determine the properties and performance of them which in turn are determined by manufacturing rote and process conditions during production stages. Horizontal continuous casting in now being considered as alternative way of conventional thermomechanical process for the production of many components. It is interesting to compare microstructure and properties of components produced by the two methods from metallurgical point of view. In the present work tensile and hardness behaviors of CuZn40Al1 alloys produced by continuous casting and extrusion were investigated. Microstructural features and fracture surfaces were studied by optical and scanning electron microscopy. Results showed that wrought samples exhibited higher mechanical properties than those of continuous cast samples. A systematic and meaningful relationship was observed between microstructural features and mechanical properties such as hardness, yield stress and ultimate tensile strength. Fractography investigations showed that fracture occurred in stop-start region in continuous cast materials.

Key-Words: - Horizontal Continuous Casting, Cast Alloys, Wrought Alloys, Two phase brass, CuZn40Al1 Alloys, Tensile Properties, Microstructure

1 Introduction

The continuous casting process has been employed for more than one century to manufacture metallic components [1]. More than 500 kinds of continuous processes have been registered during the past century [1-3]. In continuous casting, molten metal from a holding furnace is fed into a water cooled mold in which the solidification process occurs and solidified metal is taken out from the mold at the same time [4]. This means that in the process, melting, solidification and outgoing of the product occur simultaneously [2, 5]. The casting system consists of a primary water cooled mold and a water sprayed system or water pool as a secondary cooling stage [6]. The metallic shell should be thickened enough before it leaves the mold to withstand the hydrostatic pressure of remaining molten metal [4, 5]. The solidified shell is drawn out at a constant speed by a mechanical system from the mold and it is water sprayed to complete the solidification outside of the mold [4].

Continuous cast products are relatively cheaper than those produced by thermomechanical processes [1,2], but their metallurgical properties and dimensional precisions are lower [1]. Considering the advantages of continuous cast products including lower costs [4, 5], if their metallurgical and mechanical properties are acceptable, this method can replace other manufacturing processes. Therefore, understanding the process and its parameters is very useful and essential. Progress in this field has led to the replacement of many continuous cast components to those which had been manufactured by conventional thermomechanical routes [2, 7]. Various components from copper, aluminum and steel in the form of plate, strip, rod, tube and sections are produced by this method [8].

2 MATERIAL AND EXPERIMENTS

Continuous cast pipe of CuZn40Al1 produced by Zochen Company in Mashhad and extruded components produced by Semi-finished copper product company in Kerman of the same material were investigated in the present work. The casting conditions are presented in Table1. The wrought pipe is produced from billet with 105 mm initial diameter, by extrusion process at 750 oC. The internal and external diameters of pipes were 38.3 and 48.2 mm respectively for both methods. Compositions of the materials are shown in Table 2. The compositions are slightly different but they are recognized as the same material in the market, as also having the same uses. The zinc equivalent [12] is 44.81 percent for cast material and 44.76 percent for the wrought type.

Tensile specimens from the wrought and cast pipes were prepared according to ASTM E8M standard (Fig. 1). Two specimens were obtained from upper and lower parts of the pipes separately. The longitudinal direction of the samples was along the casting and extrusion directions in initial as received material. The machined samples were polished with fine sandpaper to remove any machining marks from the surface [13]. Tensile tests were conduced at room temperature using an Instron tensile machine at speed of 5×10^{-5} m/s.

The hardness of specimens was measured by an Instron volpert instrument in Vickers scale. At least 15 measurements were done for each sample and average values were reported.

Microstructures and fractured surfaces of the samples were investigated by optical and scanning electron microscopes. Samples for microstructural observations were polished by grinding paper and subsequently by diamond paste of 0.25 μm. They were etched in a solution of 20 ml acetic acid +10 ml 5 % Cr_2O_3 solution + 5 ml of $FeCl_3$ 10 % solution + 100 ml of distilled water [9].

The XRD technique was employed to identify phases in both cast and wrought samples. A stereo-microscope (Ziss stemi) was used to study fractured surfaces and find out the relationships between structural defects and fractures.

3 RESULTS AND DISCUSSION

Stress-strain curves of the two materials are shown in Figure 2, and extracted data from the curves are presented in Table 3.Results showed that wrought samples exhibited higher mechanical properties than those of continuous cast samples. An obvious difference is observed between the elastic modulus of the two materials. The elastic modulus of the cast material, resulted from tensile test, is 100 GPa. While in the case of the wrought material elastic modulus is 75 GPa.The same differences was observed before [14]. The same observed difference is related to materials not the test procedures. The above difference may be attributed to the differences between the microstructures of the two materials.

X-ray diffraction patterns of the two materials are illustrated in Figures 3 and 4. XRD patterns showed that cast material consisted of there phases α and β and γ but the wrought samples contained two phases of α and β. The existence of brittle γ-phase in the cast material may cause increases in elastic modulus. The amount, morphology and distribution of phases and also textures, which is subjected to more investigations, may lead to different behaviors of the two materials.

As shown in Figure 2 tensile properties of cast material is remarkably lower than those of wrought material. Fracture has occurred in the cast material without any appreciable plastic deformation. It is believed that the obvious differences are related to the differences of microstructures of the two materials.

Figure 5 illustrates properties in the structure of cast material at upper and lower parts in the cross section of the produced pipes. They were quantitatively evaluated by image analyzer on polished surface without etching (Table 4). At lower parts porosities are more abundant and also their shapes are more spherical. It is calculated that they are mostly gas porosities. At the upper part porosities are more irregular which may be formed due to shrinkage at the final stage of solidification. The differences in heat transfer conditions at lower and upper parts in horizontal continuous casting lead to the situation of more denderitic growth at the upper part and more columnar growth at the lower part and above difference in the formation of porosities [15, 16, and 17]. Some wormy shape cavities have been observed in the microstructure which should be farther investigated.

In the wrought material cavities and porosities are generally which less finer and than those in the cast material (Figure 6). Their shapes are also generally more rounded with less sharp corners. Their rounded shapes may have been produced during annealing in the thermomechanical processing. It is believed that thermomechanical processing improved mechanical behavior through omitting of shrinkage cracks and voids as well as improving the microstructure [18].

The fractured surfaces of cast and wrought materials are illustrated in figure 7, which is obtained by stere-microscope. The pictures reveal some discontinuities at the fractured surface edge of the cast sample. The discontinuities are more clearly depicted in figure 8 which are resulted during alternative stop and drawing of the pipe in the continuous casting process. They are observed at the internal surface of the pipe especially at the lower part. Very low ductility of the cast material observed in the tensile test is related to them as the cause stress concentration and initiates cracks which propagate leading to brittle fracture as occurred. Lack of such defects in the wrought material results in a remarkable high ductility and strength [14, 19].

Hardness measurement results are presented in figure 9. An obvious difference is observed between the hardness of cast samples in upper and lower parts, while wrought samples show the same hardness at different parts. These hardness values are surely resulted from microstructural feature in the samples as with tensile properties.

To correlate mechanical properties with microstructural conditions microscopic investigations have been done which are present in the present section. The microstructures at Upper and lower areas in horizontal continuous cast pipe are illustrated in figure 10. The light and dark areas are α and β phases respectively. The continuous β-phase forms the matrix. The morphologies of α-phase show variations in different areas which reflect the variations in the solidification conditions [20]. On the whole, α-phase grains are finer in lower part of the pipe. The volume fractions of α-phase in different areas of pipes are presented in table 5.

The solidified structured process and subsequent structural changes during cooling in solid state may be explained by equilibrium phase diagram of Cu-Zn alloys .The equivalent Zinc[12] for the present material is 44.81%. It is a double phase brass. According to phase diagram, molten metal solidifies into single phase β and during subsequent cooling some phase transformation occurs and α-phase forms. In lower parts finer β grains form and subsequently they transform into finer α grains preferentially on β grain boundaries[21].

Quantitative measurements revealed that α-phase volume fraction is lower at upper part which results in lower hardness as presented in table 5. At lower part in cast pipe microstructural features are finer and more evenly distributed which are effective in increasing hardness[11]. Figure 12 illustrates the microstructures of longitudinal and transverse sections of the wrought material. In both precipitates are elongated along the extrusion direction.

Figure 13 is an SEM micrograph of illustrating precipitates, which are observed in all areas. The precipitates can be classified into two groups of fine and coarse particles. EDX analyses of precipitates are presented in Figures 14 and 15. Coarse precipitates contain mainly Mn, Fe and Si, Mn while fine particles are mainly consisted of Mn, Si.

The observed differences in mechanical characteristics of the two investigated materials are definitely related to the differences in their microstructures and also structural defects resulted from the two different manufacturing processes. These differences include grain size and morphology [22], amount and distributions of phases [23,24], as well as defects such as voids, cracks and porosities [10].

4 Conclusion

1) The differences in mechanical properties of the two investigated materials are consistent with their microstructure differences.

2) Tensile behaviors and hardness values at upper and lower parts on the cast material are different which is consistently related to their microstructural differences homogeneous microstructure in the wrought material results in homogeneous properties.

3) Discontinuities at internal surface in the cast material resulted from horizontal casting process leads to remarkable drop in tensile strength ductility of the material. If they be removed the performance of material will improve significantly.

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Table1: The casting conditions of the pipe

Pouring tempreture	1170 °C
Drawing time	1.5 S
Drawing length	9 mm
Holding time	2.5 s
Production rate(Kg/hr)	117.7

TABLE 2. Chemical Analysis of the Materials Used in the Present Investigation, in Wt %.

Element	Cu	Zn	Pb	Fe	Mn
Cast	59	38.684	1.07	1.12	0.945
Wrought	58.848	36.0212	0.0467	0.2674	2.3659

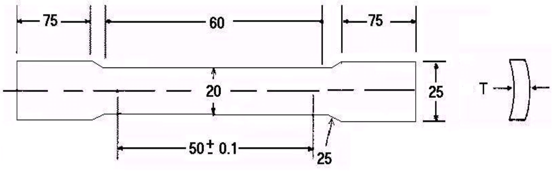

Fig. 1 : Tensile test specimen and dimensions (all dimensions are in mm)

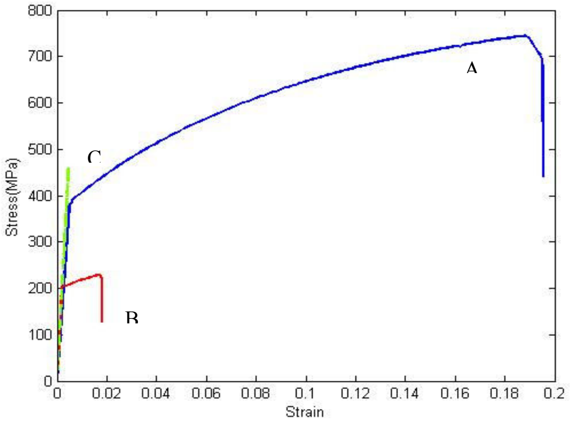

Figure 2: Stress-Strain curves of the cast and wrought pipes A) Wrought B) Cast, upper part C) Cast lower part

Table 3: Mechanical properties of the present materials

	E(GPa)	Yeild(MPa)	UTS(MPa)	El%	Hardness (Vikers)
Wrought	75	380	744	19.51	213
Cast, upper part	100	201	228.7	1.8	204
Cast lower part	100	392.3	397.2	0.46	217

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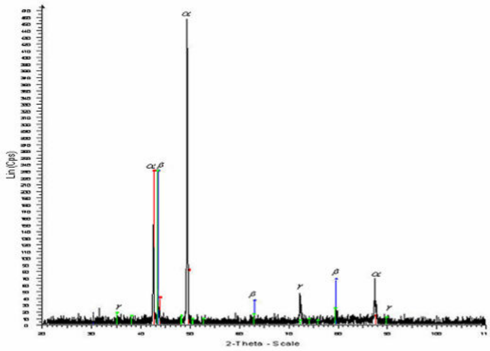


Figure 3. Diffraction pattern of cast material

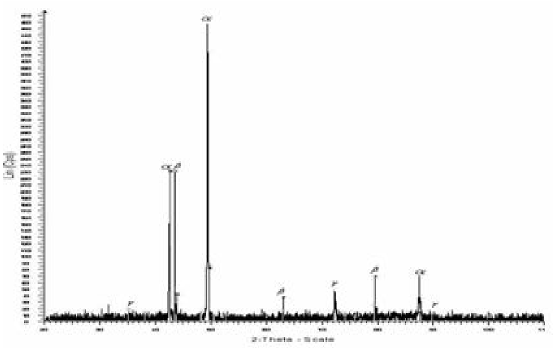


Figure 4. Diffraction pattern of wrought material.

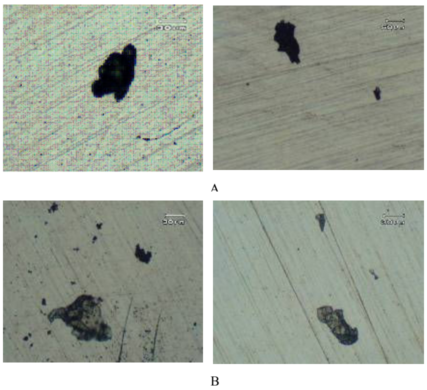


Fig. 5. Typical porosites in horizontal continuous cast pipe
A)Upper area B) Lower area

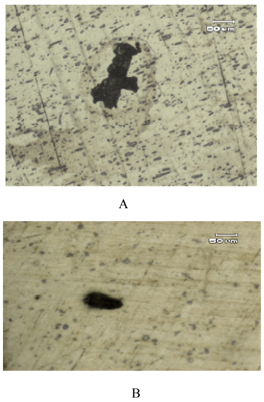


Fig. 6. Typical porosities in wrought pipe a) Extrusion direction b) Area Normal to extrusion direction

Table 4. Porosities in the polished sample ofthe horizontal continuous cast and wrought pipe.

	Round Fraction Number%	Round Fraction Volume%	Total Porosity%
Wrought	5.84	1.37	0.5
Upper area	22.6	9.12	0.858
lower area	18.27	61.15	3.99

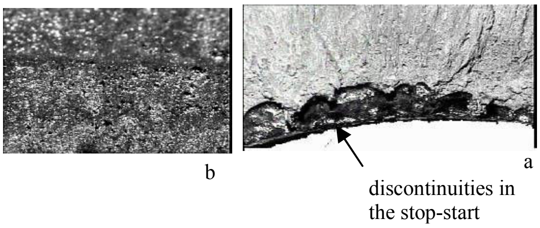


figure 7: fractured surfaces are illustrated by stere-microscope
a)cast b) wrought materials

figure 8: discontinuities which are resulted during alternative stop and drawing of the pipe in the horizontal continuous casting process

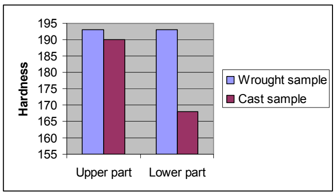
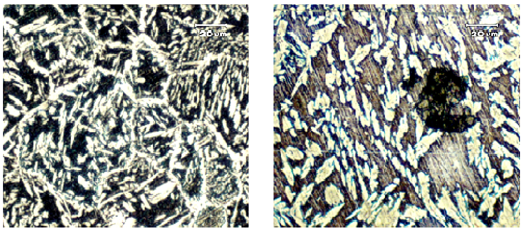


Fig. 9. Hardness variations at upper and lower parts of pipes

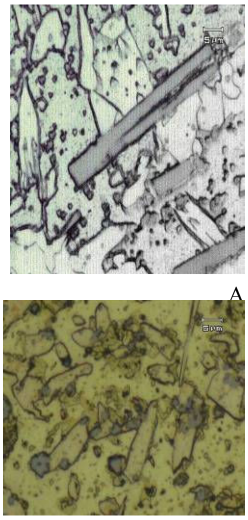


B A

Fig. 10. The microstructure of horizontal continuous cast pipe A) Upper area B)Lower area

TABLE 5. Volume Fraction of α-phase in the Microstructure.

	Wrought	Cast upper part	Cast lower part
α percentage	24.728	51.999	52.436



B

Fig. 12. The microstructure of wrought pipe
a) Extrusion direction b) Area Normal to extrusion direction