TECHNICAL NOTE

COMPARING OF MECHANICAL BEHAVIOR AND MICROSTRUCTURE OF CONTINUOUS CAST AND HOT WORKED CUZN40AL1 ALLOY

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Abstract   The performance of components produced by conventional route of a thermo mechanical process and those produced by continuous casting is interesting from different aspects of economy and technology. The performance of products in their service depends on their properties which are strongly influenced by production routes. In the present work the hardness, tensile and tensile-impact behaviors of CuZn40Al1 alloys produced by continuous casting and extrusion were investigated. Micro structural features and fracture surfaces were studied by optical and scanning electron microscopy. Results showed that wrought samples exhibited higher absorbed energy than those of continuous cast samples. Reduction of impact velocity led to a higher absorbed energy in all samples. A systematic and meaningful relationship was observed between micro structural features and mechanical properties such as hardness, yield stress and ultimate tensile strength. Fractography investigations showed that fracture occurred with dimple formation in all cases.

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چکیده   مقایسه قطعات تولیدی فرایند ریخته‌گری پیوسته و فرایندهای شکل‌دادن فلزات از جنبه های اقتصادی و تکنولوژیکی همواره توجه طراحان و متالورژیست‌ها را به خود معطوف کرده است. کارایی قطعات در حین کار بستگی به خصوصیات آنها دارد که به طور مستقیم تحت تاثیر فرایند تولید می‌باشد. در این تحقیق رفتار ضربه‌-کششی، کشش و سختی آلیاژ های CuZn40Al1 تولیدی روش ریخته گری پیوسته و اکستروژن مورد ارزیابی قرار گرفته است. بررسی های ریزساختاری و سطوح شکست بوسیله میکروسکوپ نوری و الکترونی صورت گرفته است. نتایج بیانگر انرژی بالاتر نمونه های کار شده نسبت به نمونه های ریخته گری پیوسته در آزمایش ضربه‌-کششی می‌باشد. کاهش شدت ضربه در تمام نمونه ها باعث بالا رفتن انرژی جذب شده گردیده است. ارتباط سیستماتیکی بین ریزساختار و خواص مکانیکی (حداکثر استحکام کششی، استحکام تسلیم و سختی) نمونه ها مشاهده می‌گردد. مطالعات سطح شکست نشان می‌دهد که در کلیه نمونه ها شکست با تشکیل دیمپل ها روی داده است.

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1. INTRODUCTION

The Continuous casting process has been employed for more than one century to the 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]. Molten metal is fed continuously into the system which is solidified by a cooling system [4]. 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 parameter is very useful and essential. Progress in this field has led to replacement of many continuous cast components which had been manufactured by conventional thermo mechanical routes [2,3]. Various components from copper, aluminum and steel in the form of plate, strip, rod, tube and sections are produced by this method [8].

CuZn40Al1 is a double phases high strength brass recently produced by the continuous casting process [9].This alloy has been conventional produced by a thermo mechanical method by extrusion for a relatively long time [10,11]. The presence of alloying elements such as Al, Mn, Si and Fe increases the strength. In the present work microstructure and tensile behavior of continuous cast products of the above material have been investigated and compared with those of the same material produced by thermo mechanical processing.

2. MATERIAL AND EXPERIMENTS

2.1. Material   Continuous cast components 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 used in the present work. Compositions of the materials are shown in Table 1. The compositions are slightly different but they are recognized as the same material in the market, as also having the same uses. The zinc coefficient [14] is 44.87 percent for cast material and 44.81 percent for the wrought type.

2.2. Tensile-Impact and Tensile Tests Tensile-impact specimens were prepared as shown in Figure 1. The longitudinal direction of the samples was along the casting direction and extrusion direction in these kinds of material. Each test was repeated three times. Specimen surfaces were polished by 1200 and 4000 grinding paper. The tests were done at speeds of 5×10^{-5}, 3.11, 4.15 and 5.23 m/s. Low speed tests were performed by Instron tensile machine while high speed tests were done by Roller-Amsler PK450 tensile-impact pendulum, which could be set for different angles to attain suitable impact speeds (Figure 2).

TABLE 1. Chemical Analysis of the Materials used in the Present Investigation, in wt %.

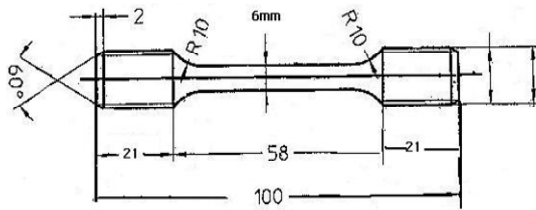| Element	Cu	Zn	Pb	Fe	Mn	Ni	Al	Si	Sn
Cast	58.1	33.868	1.4	1.71	1.45	0.171	1.35	0.091	0.496
Wrought	58.848	36.0212	0.0467	0.2674	2.3659	0.00591	1.4140	0.8729	0.10144

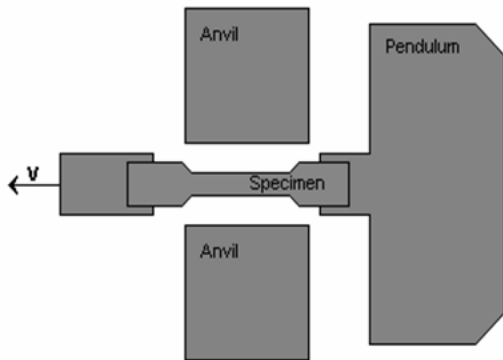**Figure 1**. Configration of specimen (dimensions are in mm).

Figure 2. The details of pure tensile-impact anvil.

2.3. Compression Test   To investigate the elastic behavior and measure elastic modulus of the materials, compression tests were also carried out. Specimens with 12 mm diameter and height to diameter ratio of 1.5 were used.

2.4. Hardness Measurements   The hardness of specimen was measured by an Instron Volpert instrument in Vickers unit. At least 5 measurements were done for each sample and average values were reported.

2.5. Metallographic and Microscopic Observations   Microstructures and fractured surfaces of the samples were investigated by optical and scanning electron microscopes. Samples for micro structural observations were polished by grinding paper and subsequently by diamond paste 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]. Some samples were electro polished and electro etched in a solution of 20 %

phosphoric acid. The microstructures were studied by optical microscope equipped with an image analyzer, enabling it to determine the fraction of phases and porosities. The XRD technique was employed to identify phases in both cast and wrought samples.

3. RESULTS AND DISCUSSION

Table 2 shows the results of tensile-impact tests of both continuous cast and wrought samples. Results show marked differences between the two kinds of materials. Wrought samples absorb more energy to fracture than those of continuously cast material. Porosities and shrinkage cracks in the cast material may lead to a lower energy for fracture. Figure 3 illustrates typical porosities in the materials. The quantitative data related to porosities and their shape characteristics are presented in Table 3. Number and volume fractions of porosities in the cast material are larger than those in the wrought material. It is difficult to determine the fraction of spherical porosities in the wrought material but the majority of them do not have sharp corners. But porosities in the cast material have generally sharp corners. Round porosities are the result of gas entrapment, while shrinkage discontinuities have sharp corners. It is believed that thermo mechanical processing improved mechanical behavior through omitting of shrinkage cracks and voids as well as improving the microstructure [13].

In cast material, shrinkage discontinuities lead to stress concentration and impair tensile and impact resistances, especially at higher strain rates. Another difference between the two materials is the presence of γ-phase in the cast material which

TABLE 2. Absorbed Energies in Tensile-Impact Test for Different Materials and Pendulum Angles.

Pendulum Angle	150°	100°	70°
Cast (J)	100.1	102.865	107.665
Wrought (J)	115.455	124.585	124.75

(a)

(b)

Figure 3. Porosities in microstructure (a) cast material (b) wrought material.

was not detected in the wrought material. X-ray diffraction patterns of the two materials are illustrated in Figures 4 and 5. The existence of brittle γ-phase in the cast material may cause a lower impact resistance and energy for fracture. With an increasing pendulum angle, in other words increasing impact speed, absorbed energy for fracture decreases in both materials, which exhibits the effect of strain rate on the fracture behavior of the materials.

Stress-strain curves of the two materials are shown in Figure 6, and extracted data from the curves are presented in Table 4. An obvious difference is observed between the elastic modulus of the two materials. To investigate the above phenomenon some samples of the materials were prepared and their stress-strain relationships in the elastic range were obtained by a compression test. Results of the compression test are illustrated in

Figure 7. The same difference is observed which means the difference is related to materials not the test procedure. The elastic modulus of the cast material, resulted from tensile test, is 100 GPa. In the case of the wrought material elastic modulus is 75 GPa. The above difference may be attributed to the differences between the microstructures of the two materials. 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.

Results show marked differences between tensile characteristics of the two materials. Yield strength of the wrought material is 539 MPa and that of cast material is 295 MPa. Their ultimate tensile strengths are 488.6 MPa for cast material and 690 MPa for wrought material. Results are consistent with previously reported values for similar material [14]. The surface area under stress-strain curve, which is a measure of absorbed energy for fracture per unit volume, is markedly larger in the wrought material. On the other hand work-hardening coefficient in the cast material is obviously bigger than that of wrought material.

The observed differences in mechanical characteristics 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 [15], amount and distributions of phases [16,17], as well as defects such as voids, cracks and porosities [10]. Manufacturing processes have profound effects on microstructure, defects and consequently on the mechanical properties which are obvious in two materials of the present study. Figure 8 illustrates the microstructures of the two materials. In both cases α and β phases together with precipitates are observable. The α-phase, in the cast material shows more directionality resulted from solidified structure, with sharper edges and corners. Table 5 presents the fractions of α phase in both materials which is larger in the cast material.

On the other hand, higher yield strength in the wrought material is attributed to finer and more homogeneous microstructure resulted from thermo mechanical processing. Coarser structure in the cast material resulted in higher strain hardening coefficient and lower ultimate strength. In the stress-strain curves, necking is not obvious but

TABLE 3. Type and Amount of Porosities in Samples.

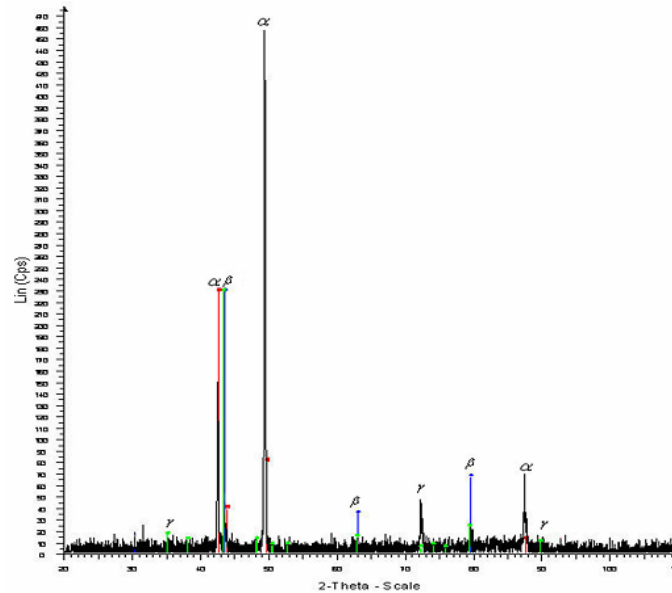|	Round Fraction Number %	Round Fraction Volume %	Total Porosity %
Cast	13.52	11.75	1.54
Wrought	14.8	2.27	1.2

Figure 4. Diffraction pattern of cast material.

there is a little decrease in stress levels in the case of wrought material before fracture. The absence of necking, in fact, is related to the significant fraction of β-phase in both materials and also to solidification defects in the cast material, which promote the fracture process. The differences in the microstructures of the two materials are also reflected in their harnesses (Table 6). In the cast material with coarser microstructure and more α-phase fraction the hardness is lower. As inferred from Figure 6, the cast material shows a more slightly elongation than the extruded one, which seems a little strange. It should be noted that the α-fraction in the cast material is 52 % while in the wrought material it is 25 % (Table 5). α-Phase has fcc structure that is more formable than β-phase

with bcc structure. This difference may be responsible for more elongation. This matter should be investigated in future works.

Fractography of fractured surfaces by SEM showed ductile fracture with dimple formations for all samples (Figure 9). In the cast material some structural defects caused the initiation of cracks (Figure 9b). In wrought samples the fracture surfaces are more homogeneous and dimples are finer, which are consistent with higher impact resistance in the material.

At higher strain rates, dimples become finer and their numbers increase. This means that at higher strain rates finer defects can be the origin of initiation and propagation of cracks leading to fracture.
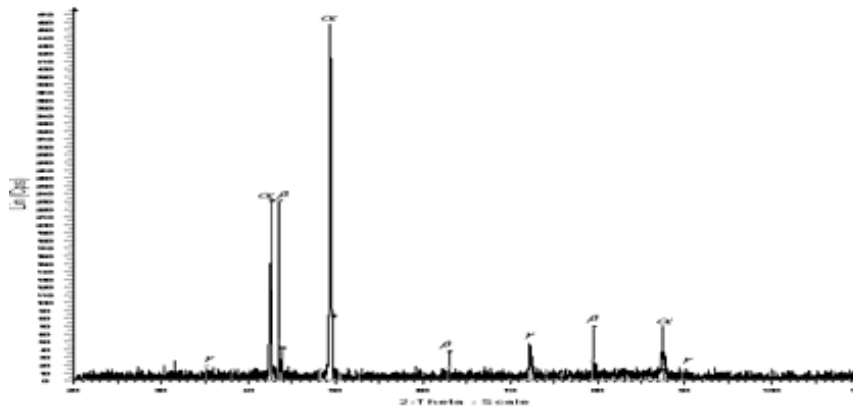
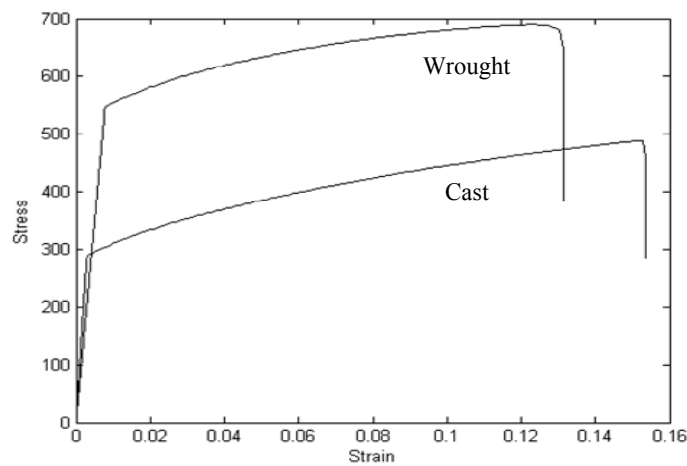**Figure 5**. Diffraction pattern of wrought material.

Figure 6. Tensile-stress strain curves of hot worked and continuous cast CuZn40Al1 alloys.
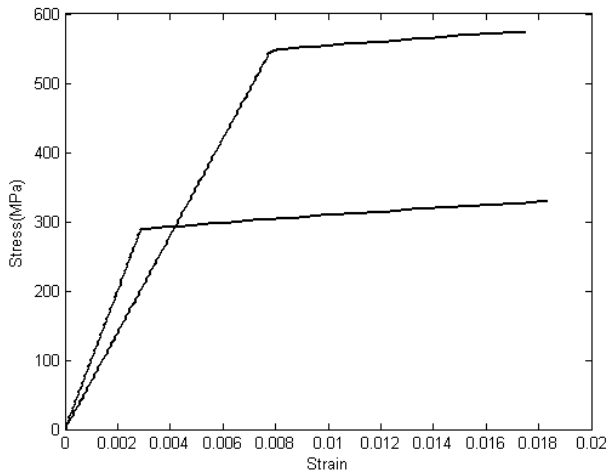
TABLE 4. Mechanical Properties of the Present Material.

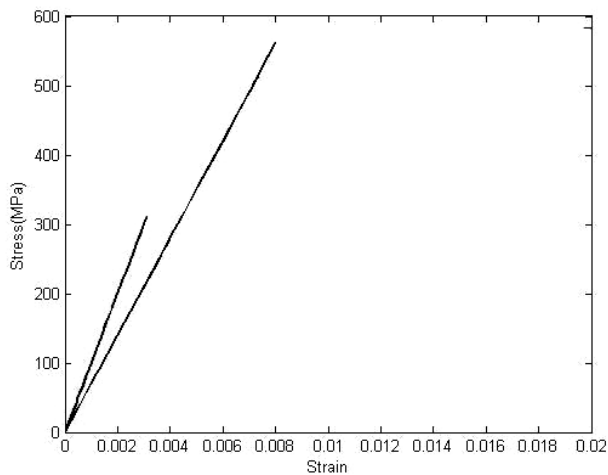|	E (GPa)	Yield (MPa)	UTS (MPa)	El %	n	K
Cast	100	295	488.6	15.5	0.4613	1581.25
Wrought	74.5	539	690	13.7	0.2708	1976.97

4. CONCLUSIONS

- Distinct differences are observed between microstructures and fractions of porosities of the two materials. The horizontal cast material contains more porosities and defects.
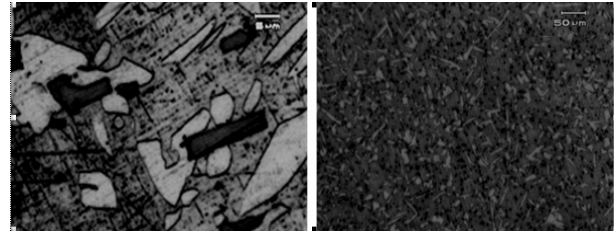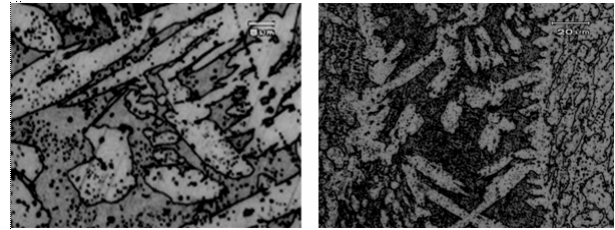
(a)

(b)

Figure 7. Stress-Strain relationships in elastic range for the two materials (a) tensile test (b) compression test.

(a)

(b)

Figure 8. Microstructures on transverse sections of (a) wrought material (b) cast material.

- The differences in mechanical properties of the materials are consistent with their microstructure differences.
- Absorbed energy of fracture for horizontal continuous cast material is less than that of wrought material.
- Yield stress and ultimate tensile strength in the wrought material are larger.
- The cast material surprisingly showed more elongation in tensile test which should be investigated in future works.

6. REFERENCES

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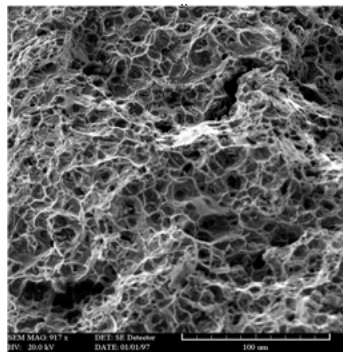**TABLE 5. Volume Fraction of α-Phase in the Microstructure.**

	Wrought Material	Cast Material
α %	24.728	52.436

TABLE 6. Measured Hardness of Samples.

Hardness (Vickers)	
Cast	Wrought
125	218
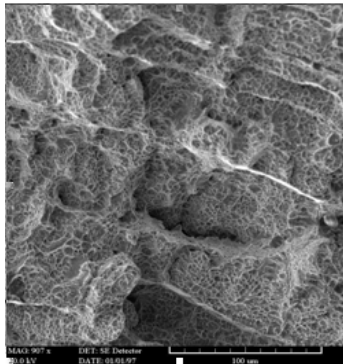
(a)

(b)

Figure 9. Fractured surfaces in tensile-impact test (a) wrought material (b) cast material.

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