Homogeneity of Microstructure and Mechanical Properties in Horizontal Continuous Cast Billet

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Abstract—Horizontal continuous casting is widely used to produce semi-finished non-Ferrous products. Homogeneity in the metallurgical characteristics and mechanical properties for this product is vital for industrial application. In the present work, the microstructure and mechanical properties of a horizontal continuous cast two-phase brass billet have been studied. Impact strength and hardness variations were examined and the phase composition and porosity studied with image analysis software. Distinct differences in mechanical properties were observed between the upper, middle and lower parts of the billet, which are explained in terms of the morphology and size of the phase in the microstructure. Hardness variation in the length of billet is higher in upper area but impact strength is higher in lower areas.

Keywords—Horizontal Continuous Casting, Two-phase brasses, CuZn40Al1 alloy, Microstructure, Impact Strength.

I. INTRODUCTION

CONTINUOUS casting first appears in the literature in 1840, but the process took over 100 years to become an industrial practice. Subsequent research has led to the development of more than 500 different techniques [1–3]. Continuous casting is a process in which there is a feed of liquid metal coming from a melting furnace to a mould which, supplied with a heat extraction system, produces the solidified metal[4]. This metal, when extracted in a continuous form, helps to establish a process of melting and continuous solidification. This process involves the melting operations, solidification, and extraction of the metal simultaneously [2, 5]. The most common being horizontal and vertical continuous casting; Copper and brass billet are widely continuously cast as semi finished products6 for various applications [3]. Horizontal continuous cast products may show in homogeneities in microstructure [7] and cross-section and dimensional variations8. The in homogeneities and dimensional variations are affected by process parameters such as casting speed8, or by heat transfer variations in

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different parts of the cross-section and water cooled mould[7, 9].

The gravity of melt alloy leads to the formation of an air gap between mould wall and solidifying metal in the upper part of the mould during horizontal continuous casting [10], thus reducing heat transfer at the upper part. The total heat transfer coefficient in the upper part is:

$$\frac{1}{h_{upperpart}} = \frac{l_{metal}}{K_{metal}} + \frac{\delta}{K_{air}} + \frac{l_{mould}}{K_{mould}} + \frac{1}{h_w} \qquad (1)$$

But in lower part a term of δ/K air is omitted because of gravity of melt [11]. Effect of this heat transfer variation at upper and lower part of horizontal continues casting pipe was studied by the Authors of this paper at last work [12]. In the present work, the microstructure and mechanical properties of a continuous cast billet of CuZn40Al1 alloy have been studied.

II. MATERIAL AND EXPERIMENTS

A CUZN40Al1 two phase brass in the form of horizontal continuous cast billet was investigated. The diameter of the billet was 105 mm. The casting production conditions are presented in Table I and the chemical composition of the brass is given in Table II.

Samples were cut in cross sectional direction, as shown in Fig. I, to compare the microstructures in the length of billet in Y direction. The impact samples prepared from the upper, middle and lower area of billet that marked by (×) in fig. I.

The microstructures and porosities were studied by optical microscopy. Metallographic cross-sections were polished on 120 to 4000 grade paper and subsequently using 0.25 mm diamond paste, then etched in a solution of 20 mL acetic acid, 10 mL 5%Cr2O3, 5 mL 10%FeCl3 in 100 mL distilled water. Some samples were electro polished and then electro etched in a solution of 20% phosphoric acid. The volume fractions of phases present and porosity were characterized using an optical microscope equipped with an image analyzer.

Notchless specimens 13 of the shape and dimensions shown in Fig. II were used for the impact tests. Four specimens were obtained from the upper, middle and lower parts of pipes respectively.

Hardness was measured using a Vickers tester with a load of 19.987 N. Values reported are averages of five measurements. The Microhardness of α-phase was measured by a Struers Duramin 20 instrument in Vickers unit with a load of 1.987 N. At least 5 measurements were done for each

sample and average values were reported.

III. RESULTS AND DISCUSSION

Figure III illustrates pores at the upper, middle and lower areas of the horizontal continuous cast billet in cross-section. The average pore size of porosities is larger in the upper area, and pore morphology is more spherical in the lower area(Table III). The volume fraction of porosity was 3.45% in upper area but only 0.75% in the lower area. In the lower region 30.94% of pores are spherical, but only 5.94% in the upper region.

The differences in pore shape can be attributed to variations in the heat extraction and solidification conditions. In the lower part, the solidification rate is higher, [11] since gravity leads to the formation of an air gap between mould wall and solidifying metal in the upper part of the mould,[12] thus reducing heat transfer. The finer porosity in the lower part reflects the more rapid solidification rate arising from the higher heat flow, as does the finer, more scattered pore distribution. In the upper part, the lower solidification rate provides more time for gas bubbles to coalesce to form larger discontinuities that are generally more irregular in shape. In the investigation on microstructure and mechanical properties of horizontal continues cast pipe of CuZn40Al1 alloy the porosities in the upper and lower part of pipe have the same behavior[12].

The behavior of porosities in the middle areas of the billet is between upper and lower areas. The distribution of porosities at the length of billet in Y direction is shown in Fig. IV. As shown in Fig. IV maximum percentage of porosities is about 24 cm upper from the Geometrical center of billet.

Typical microstructures are illustrated in Fig. V, in which the light areas are α phase and the dark areas the β matrix. The morphology of the α-phase reflects the solidification conditions,[14] being generally finer in the lower part of the billet. The volume fraction of β phase observed was 26.25 vol. % in the upper region, 25.15 Vol. % in the middle region and 22.95 vol. % in the lower region.

The solidification process and structural changes during cooling may be interpreted in terms of the Cu–Zn equilibrium phase diagram (Fig. VI). The zinc equivalent [15] for the present two-phase brass is 44.60%. The molten metal solidifies as primary β, which during subsequent cooling partially transforms to α. In lower region of the billet, finer β grains form owing to the higher solidification rate; here the α phase is finer and nucleates preferentially at β grain boundaries[16].

In lower areas with decrease in cooling rate, percentage of α-phase decreased in comparison to the middle and upper area. The distribution of volume fraction of β-phase at the length of billet in Y direction is shown in Fig. VII. Maximum percentage of β-phase is about 35 mm upper from the Geometrical center of billet.

Comparison between behavior of diagrams in Fig. IV and VII is attractive. In the solidification of billet a maximum percentage of porosities are at the area with lowest heat transfer rate[12]. As shown in Fig. IV this area is about 24 cm upper from geometrical center of billet. Lower heat transfer rate in the length of billet at CuZn40Al1 alloy causing maximum β-phase stability[17]. As shown in Fig. VII this area is about 35 mm from the geometrical center of billet. The difference between these two distance in the length of billet need more investigation, but existence of maximum percentage of porosities after solidification at 24 cm upper from geometrical center is the main reason that affect on heat transfer and transformation of β-phase to α-phase[16].

As shown in Fig. IV and VII diagrams after a maximum point, fall down. The reason of this phenomena is high heat transfer rate at the beginning of solidification and the time that air gap is not formed, or thin solidified layer in the beginning of solidification in upper area.18

Spherical precipitates are observed in all areas. A typical image of the precipitates was shown and investigated by Authors [12] in last work on CuZn40Al1 alloy. The precipitates could be classified as fine and coarse. The coarse precipitates mainly consist of Mn, Fe and Si, whereas the fine particles mainly consist of Mn, Fe, Si, Al and Ni. It is proposed that the coarser precipitates form during solidification, whereas the finer particles may form in the solid state, e.g. during subsequent heat treatment [12].

The absorbed energy recorded in the impact test was 98.61 J in the upper, 100.63 J in the middle and 119.85 J in the lower part of cross section of billet. The higher impact energy in the lower region may be attributed to the smaller volume fraction of porosity. Also, pores in the upper region are mainly shrinkage pores [12] with sharper corners that detriment alloy affect impact strength. The higher volume fraction and continuity of a phase in the lower regions may also exert a positive influence but this effect is thought to be less important.

Distribution of Hardness at the Length of billet in Y direction is shown in Fig. VIII. Hardness measurements show that the upper areas at the Length of billet in Y direction are slightly harder than the lower and middle areas. Lower α-phase volume fraction at upper parts may result in higher hardness as shown in Figure VII and VIII. The distributions and morphologies of α and β phases may also affect the hardness of the alloy[19], which may be influenced by solute contents of each phase in the form of solid solution. Micro hardness variation of α-phase at the length of billet in Y direction is shown in Fig. IX.

As shown in Fig. IX micro hardness variation in the length of billet is constant. From Fig. VIII and IX, the hardness is not affected by solute constant of each phase, but the effect the percentage of phase in the length of billet.

IV. CONCLUSION

1. The microstructure of the two phase brass horizontal continuous cast billet showed distinct variations in the length of the cross-section. The upper region of the

cross-section contained a higher volume fraction of porosity, and the pores were larger and more irregular in shape. The microstructure was coarser in the upper region, reflecting the lower solidification rate.

2. The hardness of specimens from the upper region of the cross-section was higher than corresponding values for the middle and lower region, but micro hardness variation in the length of billet is constant. This is attributed to the difference in volume fraction, morphology and connectivity of the phase.

3. The impact energy of specimens from lower region of the cross-section was larger, a fact attributed to the detrimental effect of large irregular pores in the upper region.

4. Observed maximum in Fig. IV and VII and the situation and relation of them need more investigation.

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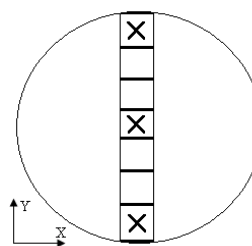
Fig. 1 Schemetic of metallograghy samples at different parts of the billet (×) area that impact samples manufactured

TABLE I
THE CASTING PRODUCTION CONDITION BILLET

Casting condition	Billet
Diameter	105 mm
Pouring temperature	1170 oC
Drawing time	2 S
Drawing length	35 mm
Holding time	30 s

TABLE II
CHEMICAL ANALYSIS OF THR MATERIALS USED IN THE PRESENT INVESTIGATION, WT %.

Element	Cu	Zn	Pb	Al	Mn	Ni
Billet	59.200	35.677	0.992	1.100	1.230	0.240

TABLE III
CHARACTERISTICS OF POROSITY OBSERVED IN MICROSTRUCTURE OF HORIZONTAL CONTINUOUS CASTING

	Round Friction Number%	Round Friction Volume%	Total Porosity %
Upper area	17.05	5.94	3.45
Middle area	15.77	15.50	2.50
Lower area	26.35	30.94	0.75
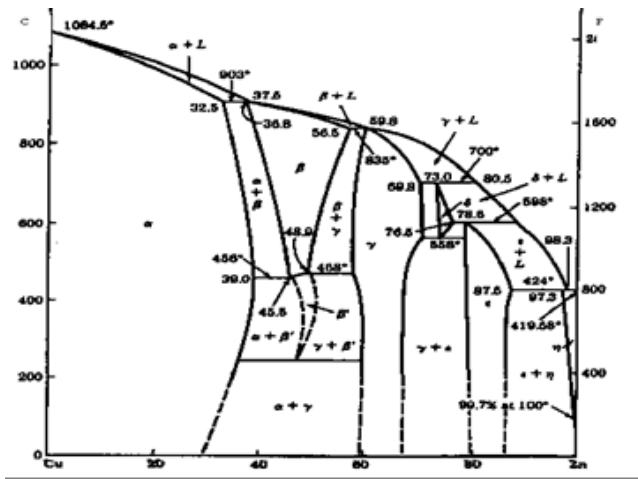
Fig. VI
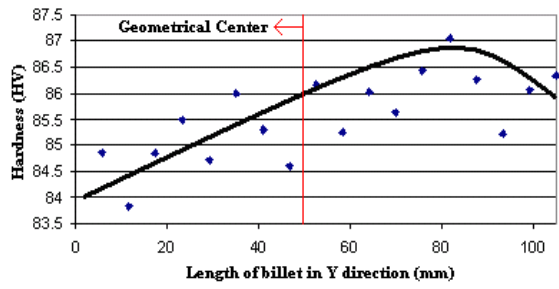Equilibrium Phase Diagram of Cu-Zn Alloy

Fig. VIII
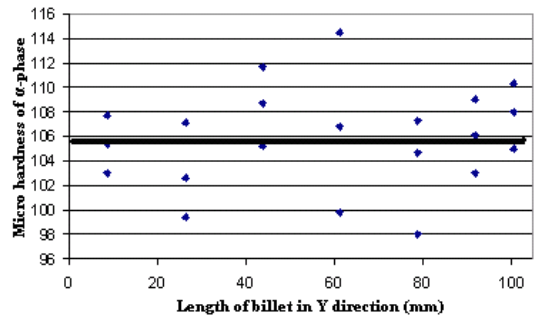Hardness variation at the length of billet in y direction

Fig. IX
Micro hardness variation at the length of billet in y direction

Fig. VII
Distribution of Volume Fraction of B- Phase at the Length of Billet in
Y Direction