

INFLUENCE OF CASTING SPEED ON THE STRUCTURE AND MECHANICAL PROPERTIES OF CONTINUOUS CAST DHP COPPER TUBE

Ehsaan-Reza BAGHERIAN^a, Colin BELL^b, Mervyn COOPER^b, Yongchang FAN^a, Brian FRAME^b, Amin ABDOLVAND^a

^a University of Dundee, DD1 4HN Dundee, Scotland, United Kingdom,
e.bagherian@dundee.ac.uk, y.fan@dundee.ac.uk, A.Abdolvand@dundee.ac.uk

^b Rautomead Ltd, DD2 4UH Dundee, Scotland, United Kingdom
Colin.Bell@rautomead.com, Mervyn.Cooper@rautomead.com, Brian.Frame@rautomead.com

Abstract

DHP Copper tubes are frequently used in industrial applications with their unique characteristics such as high corrosion or excellent erosion resistance. Due to the requirement of good quality production, an excellent global factor is needed for the purpose of obtaining high mechanical properties. A mechanical properties has correlation with grain size and a high mechanical properties is achieved by small grain structure. There are three ways in which grain size can be altered: by thermal means, chemical means and by mechanical means. This paper looks at the first case, thermal means, which has very substantial cost benefits over the other two types of grain refinement in that it does not require large pieces of equipment that vibrate or mix and does not use any exotic metals as feed stock. Instead what thermal methods require is a change in parameters like: casting speed, liquid metal temperature or cooling water temperature. In this work, characterization of the influence of casting speed on the structure and mechanical properties of continuous cast DHP copper tube has been carried out by drift expanding test and grain size reading. A significant different based on grain structure has been investigated and it was also found that the casting speed could improve the elongation of samples from 29 % expanding to 36 % expanding.

Keywords: DHP Copper Tubes, Casting Speed, Drift Expanding Test and Grain Structure

1. INTRODUCTION

In alloy castings it is usually desirable for the grain structure to be fine. The major advantage of fine grain structures over cast structures is the improvement of mechanical properties and increase uniformity of properties [1, 2]. The fine grain process development program begun in 1975 to produce a fine, equiaxed grain structure with a vacuum-cast IN713LC radial turbine wheel and since the 1980s, fundamental fine-grained cast techniques have been widely developed [3]. Grain refining methods are grouped into (a) thermal such as cooling rate control, (b) chemical by adding the nucleant agents addition into the melt and (c) dynamical by mechanical agitation [4, 5].

Although a finer grain can be obtained by mechanical and chemical techniques but the problem of these methods are that, the mechanical way is expensive and inoculants introduce oxides, which as non-metallic inclusions, become nucleation sites for fatigue crack initiation [3]. The other problem of chemical method is lack of uniform dispersion of nucleant agents like metal oxides due to the ultimate problems such as poor wettability or in-compatibility between metal and oxide particles [6].

In this work, characterization of the influence of parameters of the casting process has been carried out, especially that of the casting rate was selected as the most adaptable technique and the easiest to implement in a conventional casting process. However, the casting speed is limited by several different phenomena examples of fracture of samples on high-speed solidification rate. Clearly, to increase the casting speed of a continuous casting process requires careful consideration of many different phenomena.

The aim of this paper is to investigate the impact of the casting speed on the structure and mechanical properties of continuous cast DHP copper tubes.

2. EXPERIMENT

The traditional method of producing copper tube is by large ingot casting and extrusion but there is a new method which use continuous casting technology to cast smaller tube. The main advantage of the continuous casting process for copper tube production is that it is an economic and flexible manufacturing process with a much smaller initial capital investment.

In studying the properties of DHP copper tubes it is necessary to have detailed knowledge of mechanical properties and grain size of the samples. Mechanical properties usually gain by 3 testing methods involving; (a) Tensile test by inserting a metal plugs into the ends of pipe and then measuring the tensile strength and elongation percentage, (b) Tube drift expanding test to measuring the tube expanding percentage and (c) Flattening test for determining the ability of metallic tubes of circular cross-section to undergo plastic deformation by flattening [7, 8 and 9].

In order to understand the efficiency of casting speed, further study has been done. Four casting speed have been studied in this research (1040 (mm/min), 1140 (mm/min), 1220 (mm/min) and 1360 (mm/min) respectively) and mechanical properties of continuous cast DHP copper tubes has investigated by drift expanding test.

Table 1 is given the copper tube samples tested in this study.

Table 1 The Copper tube samples tested in this research

Sample	OD (mm)	Thickness (mm)	Speed (mm/min)	Product (kg/hr)
Cast 1	38	2.3	1040	144
Cast 2	38	2.3	1140	158
Cast 3	38	2.3	1220	169
Cast 4	38	2.3	1360	189

Drift Expanding Test – drift-expanding test is “Expansion of the end of the test piece cut from the tube, by means of a conical mandrel, until the maximum outside diameter of the expanded tube reaches the value specified in the relevant product standard” [7].

Symbols, designation and units for the drift-expanding test of tubes are presented in **Table 1** and shown in **Fig. 1**. **Fig. 2 (a and b)** illustrates the test procedure, which have been carried out to identify the Influence of casting speed on the mechanical properties of continuous cast DHP copper tubes.

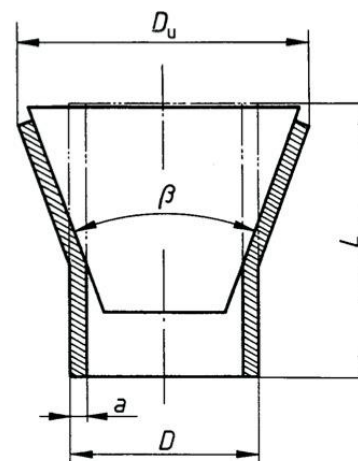


Fig. 1 Designation of the drift-expanding test of tubes

Table 2 Symbols, Designation and Units for the drift-expanding test of tubes

Symbol	Designation	Units
A	Wall thickness of the tube	mm
D	Original outside diameter of the tube	mm
Du	Maximum outside diameter after testing	mm
L	Length of the test piece before testing	mm
B	Angle of the conical mandrel	Degree

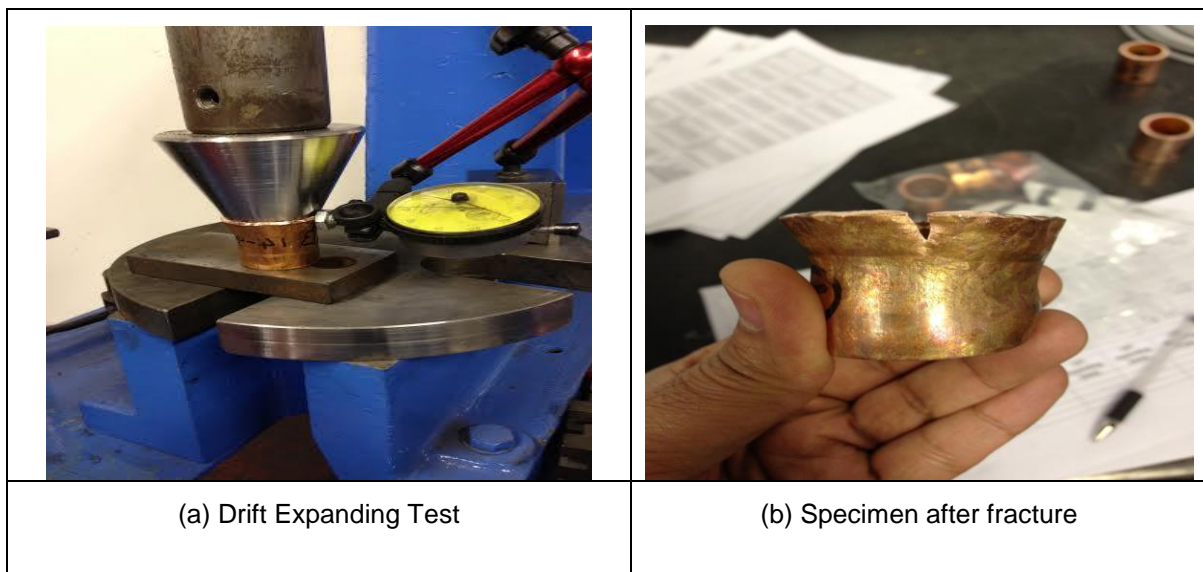


Fig. 2 drift-expanding procedure

In this research, drift expanding test done by a hydraulic press at ambient temperature and truncated-cone shaped mandrel of hardened steel. The length of the specimen was selected less than twice size of the external diameter of the tube. Finally, the drift expanding percentage, calculated by measuring the diameter of tube after fracture divided by the original diameter of tube

Metallography – Metallographic analysis is the science of preparing a metal surface by grinding, polishing and etching to study the metal alloy’s microstructures, which usually determine the physical and mechanical properties of metal alloy material [10]. In this paper, all samples were ground first using coarse abrasive paper (Grade No 60) and subsequently wet & dry fine silicon carbide paper (Grit No 2500). Then the samples were polished using diamond paste beginning with 6 micron and then continuing until the grinding scratches were removed (quarter micron). After polishing, the samples were cleaned by acetone in an ultrasonic cleaner and dried with nitrogen gas. Finally, the polished samples were etched using a cotton tip dipped with distilled water and nitric acid.

3. RESULTS AND DISCUSSION

Average Expanding Percentage –The results of average expanding percentage of copper tube samples are presented in **Fig. 3**. **Table 2** shows the average expanding percentage of the continuous cast DHP copper tube samples, which explained on **Table 1**. It can be seen that the cast 4 samples has a higher drift expanding percentage (improved by 29 % to 36 %)

Table 3 Drift expanding results

Sample	Test 1	Test 2	Test 3	Average Expanding Percentage (%)
Cast 1	31 %	28 %	27 %	29 %
Cast 2	30 %	32 %	28 %	30 %
Cast 3	32 %	31 %	33 %	32 %
Cast 4	38 %	35 %	36 %	36 %

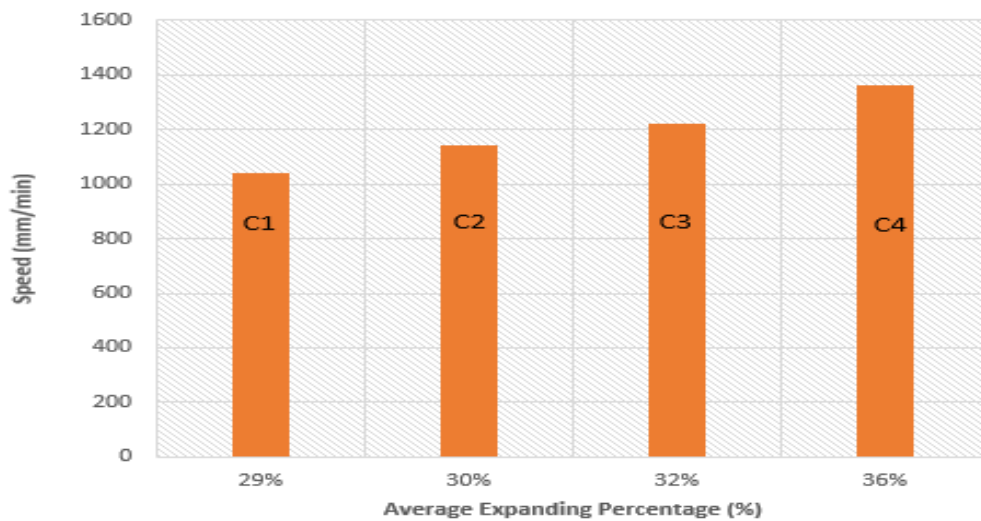
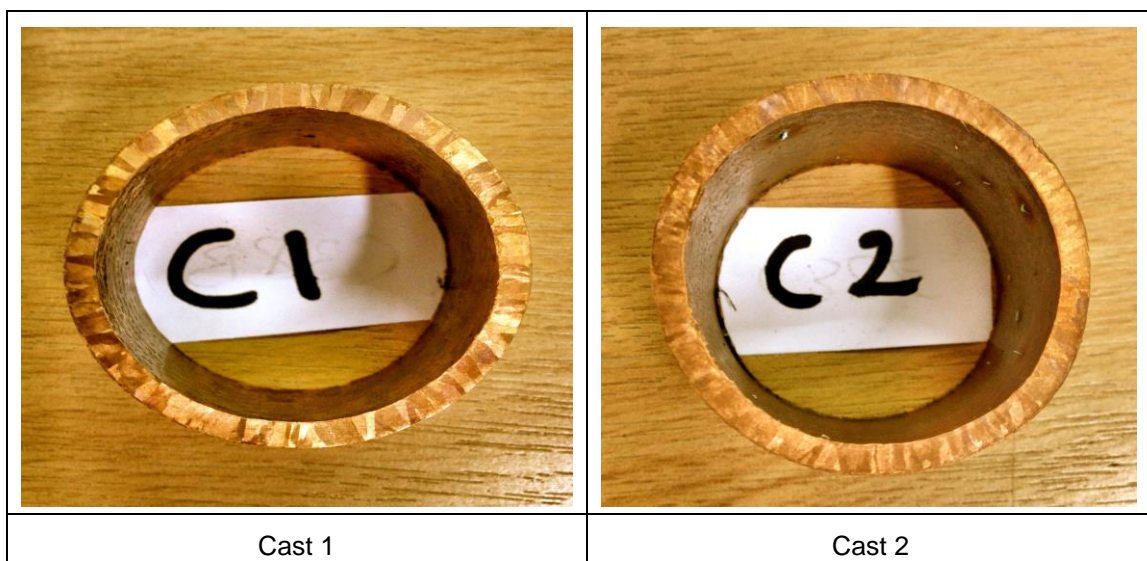


Fig. 3 comparison average expanding percentage of copper tube samples

Grain Structure – The effect of casting speed on the structure of the continuous cast DHP copper tube is illustrate in **Fig. 4**. It must be noticed that fine grains can be achieved by increasing the casting speed, as seen in sample 1, 2, 3 and 4 in **Fig. 4**.



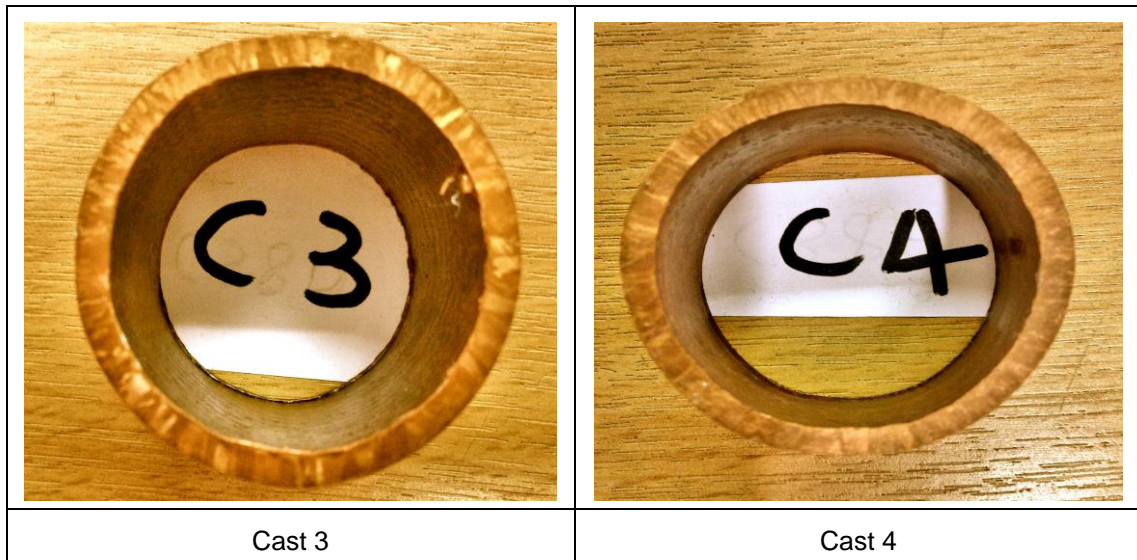


Fig. 4 comparison grain structure of copper tube samples

An easy method to expand the mechanical properties of a material is to make the grain size as small as possible, or to increase the amount of grain boundaries.

It is known from the above observation on the metallography analysis of grains that the number of columnar grains increases after grain refining by increasing the casting speed. As is well known, smaller grains have greater ratios of surface area to volume, which means a bigger ratio of grain boundaries to dislocations. The more grain boundaries that occur, the higher strength.

The other reason for this is increasing casting speed leads to a change in the heat conduction and solidification condition, which results in making it possible to obtain a structure with finer grains. This is based on a thermal change because the higher the casting speed gets the faster the material goes from liquid to solid.

4. CONCLUSION AND FUTURE WORK

From the above experimental results, some important conclusions can be drawn:

1. Once the speed is increased from 1040 mm/min to 1360 mm/min the end result produces an increase in the production rate from 144kg/hr to 189kg/hr.
2. When casting speed was increased from 1040 mm/min to 1360 mm/min, significant improvements of mechanical and physical properties were observed. With the increasing of the casting speed, the drift expanding percentage increased, and the grain structure tends to become finer in structure.
3. An economical process has been studied to produce continuous cast DHP copper tube fine grain structure by increasing the casting speed. A significant achievement of the fine grain process is to produce a uniform structure and enables greater reliance to be placed on the manufacturing process.
4. One limitation observed in this study is that once the casting speed is increased above the 1360 mm/min by even a minute amount it would result in a casting fracture. Thus, at high casting speed, casting speed changing should be avoided or slower speed changing rate in continuous casting should be used.
5. As for future work, this research can be extended by comparing the influence of other thermal factors on the structure and mechanical properties of continuous cast DHP copper tube such as; the temperature of liquid metal or cooling water temperature.

6. It is suggested that for extended future work to these areas, a chemical way could also be attempted.

ACKNOWLEDGEMENTS

The corresponding authors would like to thank Mr. Gavin Marnie, Mr. Dougie Hain and Mr. Graham Lees at Rautomed, and Professor Mervyn Rose and Dr. Mark Pridham at University of Dundee, for their technical support.

LITERATURE

- [1] T. E. Quested, A. L. Greer, Grain refinement of Al alloys: Mechanisms determining as-cast grain size in directional solidification, *Acta Materialia*, Volume 53, Issue 17, October 2005, pp. 4643–4653
- [2] J. R. Bringer, L. F. Norris, L. Rozenberg, Microcast-x fine grain casting a progress report, Super alloy 1984, The Metallurgical Society of AIME, 1984, pp. 23 - 32.
- [3] M. Would, H. Benson, Development of conventional fine grain casting process, The Metallurgical Society of AIME, 1984, pp. 3 -12.
- [4] L. F. Mondolfo, Grain refinement in the casting of non-ferrous alloys, Grain Refinement in Casting and Welds, The Metallurgical Society of AIME, 1983, pp. 3-50.
- [5] T. Robert, M. E. Noguez, G. Salas, S. Montejano, Influence of grain refinement on some mechanical properties of non ferrous cast alloys, *Acta Metallurgica et Materialia*, Volume 40, Issue 4, April 1992, Pages 771–777.
- [6] Gwang-Ho Kim¹⁾, Sung-Mo Hong²⁾, Min-Ku Lee, Effect of Oxide Dispersion on Dendritic Grain Growth Characteristics of Cast Aluminum Alloy, *Materials Transactions*, Vol. 51 No.10 (2010) pp.1951-1957.
- [7] ASTM, Standard Test Methods and Definitions for Mechanical Testing of Steel Product, A 370 – 07b
- [8] EN ISO, Standard Test Methods and Definitions for Metallic materials – Tube - Drift-expanding test, 8493:1998.
- [9] EN ISO, Standard Test Methods and Definitions for Metallic materials –Tube - Flattening test, 8492:1998.
- [10] Metallography, Microstructure, and Analysis, Application and Innovation for Metals, Alloys, and Engineered Materials, ISSN: 2192-9270 (electronic version) Journal No. 13632.