ANALYSIS AND QUANTIFICATION OF MECHANICAL PROPERTIES OF VARIOUS DHP COPPER TUBES MANUFACTURING PROCESSES USING DRIFT EXPANDING TEST

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Abstract

Deoxidized High Phosphorus (DHP) Copper tubes are frequently used in numerous industrial and household applications. To ensure the acceptability of DHP copper tubes prepared by various industrial processes, the quality of the DHP copper tubes must be evaluated. Drift expanding test is one of the best ways to do so is to examine the quality of tubes. In this paper the authors considered the mechanical properties of various DHP copper tubes manufacturing processes using drift expanding test. This paper concludes that there is a large difference in the mechanical properties of tubes with different manufacturing methods. Planetary rolling have a better expanding percentage than cast or extruded tube samples.

Keywords: DHP copper tube, drift expanding test, continuous casting, planetary rolling, drawing

1. INTRODUCTION

The using of copper tube has increased importance in many applications and industries over the decades. Currently the usage of copper tube has grown over the last few years mostly due to their beneficial characteristics such as high corrosion resistance, high thermal-exchange efficiency, excellent erosion resistance and easy processing. Apart of this copper has a long useful life and is environmentally friendly - 100% recyclable, lightweight, and easy to join. These properties made copper as the cost effective material for tube application [1]. The main applications of copper tubes can be classified into three major categories: (a) water or plumbing tubing, (b) air conditioning and refrigeration tubing and (c) industrial applications [2, 3]. In recent years, copper tubes have been gradually replaced by inner-grooved ones to improve the efficiency of thermal-exchange for energy saving and environmental protection. Based on the statistics of the Chinese refrigerating industry union, the demand for household air conditioners was 30.5 million, which means that 91.6 thousand tons inner-grooved copper tubes needed [4].

The traditional method of producing copper tube is by large ingot casting and extrusion but there are new methods which use continuous casting technology to cast smaller tube. One of the proven new processes for casting smaller tubes is the planetary rolling process, which casts a much smaller hollow billet. Another new process which has just been developed is the cast-tube process which produces a continuously cast tube shell at a size suitable for drawing. 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 [5].

The main purpose of this study is to investigate the mechanical properties of the DHP copper tube samples prepared by typical industrial processes as motioned above using drift expanding test.

2. EXPERIMENT

2.1. Material preparation and casting procedure

Deoxidized high phosphorus (DHP) copper is the common alloy which is used for copper tubes. It usually contains 0.015 to 0.040 wt.% phosphorus to ensure freedom from residual oxygen. As shown in **Figure 1**, there are three methods available for producing the copper tubes, including (1) the traditional method, (2) the established method and (3) the new method. Each has its specific characteristics, as well as advantages and disadvantages. The following sections explain the various copper tube production methods and their characterizations.

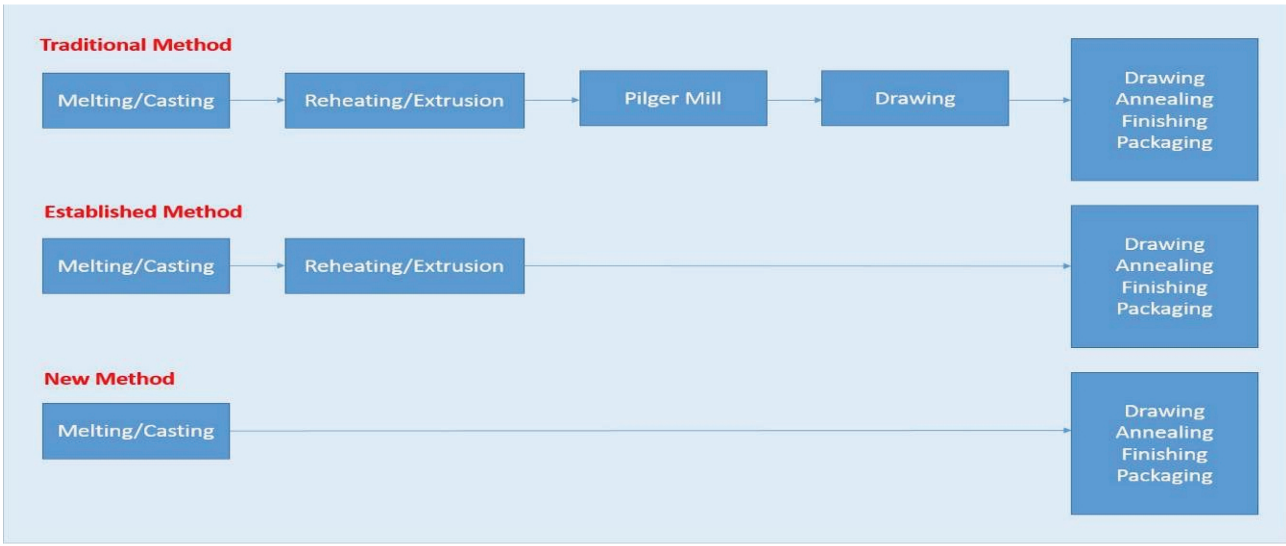


Figure 1 Schematic of various DHP copper tubes manufacturing process

2.1.1. Traditional method (continuous copper tube extrusion)

This method has been used for many years. In order to produce copper tubes by continuous extrusion procedure, a copper cathode is first melted and cast into a billet. The billets are then reheated using a proper hot-working temperature, and extruded into large tubes or shells. Because the shells are too large to bend, a special linear machine, known as a pilger mill, is used to draw the shells to a 'mother' tube. Last steps are (a) drawing, (b) annealing and (c) finishing/packaging respectively.

a) Drawing simply involves pulling the hollow tube through a series of hardened steel dies to reduce its diameter.
b) Annealing: drawn tubes are then passed through a continuous annealing furnace in order to improve its mechanical properties.
c) Finishing/Packaging are the final steps. The tube may be cleaned to remove any traces of previous steps.

The key advantage of this method is continuous operation for high efficiency. However, the investment costs for a pilger mill is fairly high. Maintenance of the extrusion method is also expensive [6].

2.1.2. Established method (planetary rolling)

The three-roll planetary rolling mill is a especially process for DHP copper tube making which is consist of (a) a cylindrical mandrel located inside and fixed in position by axially adjustable clamping devices (b) three uniform distributed conical rollers and (c) the external ring. By the rotation of the roller, the copper tube billet is compressed and rotated around the mandrel to the forward direction. This method has expensive capital investment but compared to the extrusion its feature of smaller number of process steps [7, 8].

Figure 2 shows the schematic of the three-roll planetary mill.

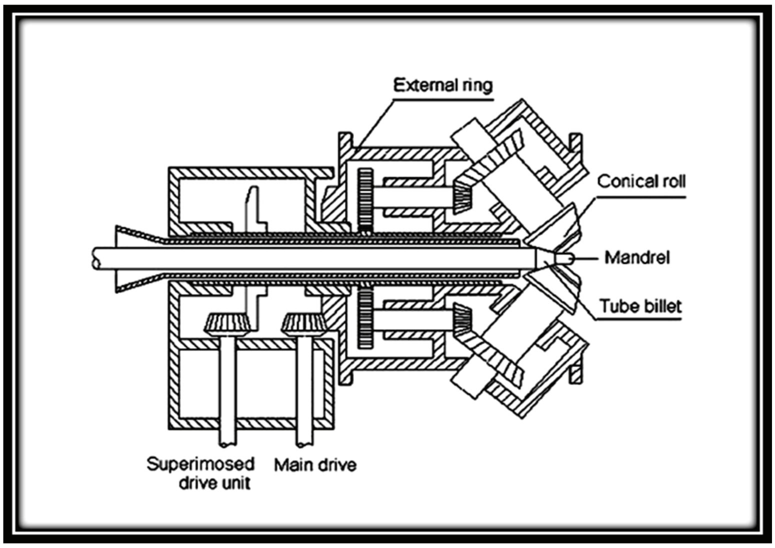


Figure 2 Schematic of the three-roll planetary mill

2.1.3. New method (continuous casting)

The new method which is consisted of melting and casting have several advantages compared to the extrusion and planetary rolling process. The key advantages include [9]:

1. Lower capital investment. This method is about 6-8 times cheaper than planetary rolling which itself is already half the price of the traditional extrusion based process.
2. Less operation. This method is only about 25% of a large planetary rolling unit and even much less when compared to the extrusion method.

So if the metallurgical and mechanical properties of the component produced by continuous casting are acceptable, this method can be replaced to two other methods.

The main purpose of this study is to investigate the physical and mechanical properties of the DHP copper tube samples prepared by typical industrial processes as mentioned above. The representative DHP copper tube samples analysed in this work and their corresponding processes are listed in **Table 1**.

Table 1 The Copper tube samples tested in this research

No	Sample	Process
1	As cast	Cast at 38 x 2.3 mm
2	Drawn	Cast at 38 x 2.3 mm drawn to 30 x 1.85
3	Annealed	Cast at 38 x 2.3mm drawn to 32 x 1.75 then drawn to 28 x 1.35 then batch annealed
4	Planetary rolling	Cast at about 100 x 25 mm, then rolled to 58 x 3 mm
5	Extruded 1st	Extruded to 70.45 x 3.1 mm, then drawn to 29 x 1.1 mm
6	Extruded 2nd	Extruded to 70.45 x 3.1 mm, then drawn to 24 x 1 mm

2.2. 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". The length of specimen is dependent on alloy materials for example for aluminum and light alloy tube the length of the specimen is to be not less than twice the external diameter and for copper and copper alloy tubes, the length of the specimen is to be not less than twice but not more than three times the external diameter of the tube. To perform this test, the test specimen is expanded by a mandrel until it fractures.

After test, on the surface of tube and the expanded zone of the specimen, in addition to the fracture may not be visible any cracks. In this research, drift expanding test done by a hydraulic press at ambient temperature and truncated-cone shaped mandrel of hardened steel [10, 11].

Symbols, designation and units for the drift-expanding test of tubes are presented in **Table 2** and shown in **Figure 3**. **Figure 4 a)** and **4 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.

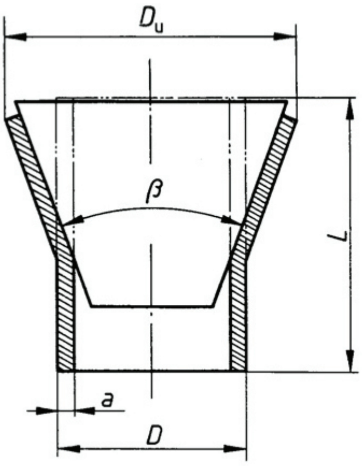
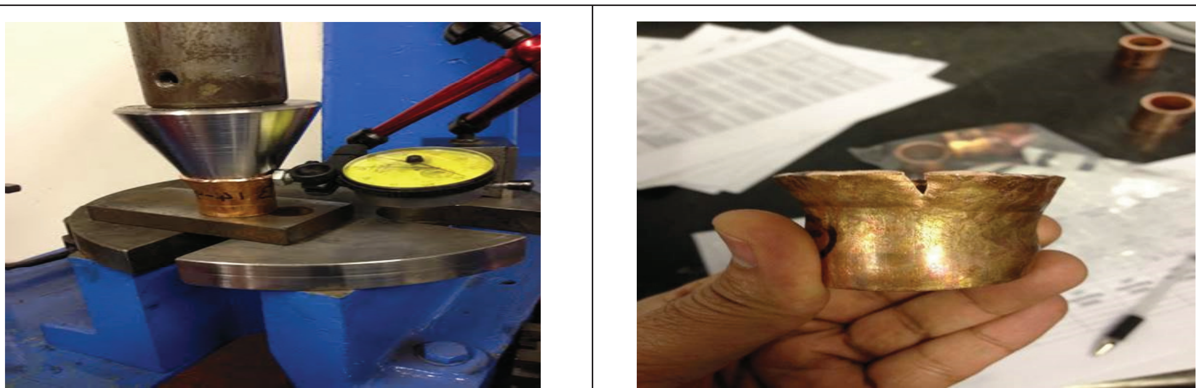


Figure 3 Designation of the drift-expanding test of tubes

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)



(a) Drift expanding test

(b) Specimen after fracture

Figure 4 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.

3. RESULTS AND DISCUSSION

Compare the mechanical properties of the DHP copper tube samples prepared by various industrial processes was investigated using the tube drift expanding test. The calculated data and the drift expanding test results are illustrated in **Table 3**.

Table 3 Drift expanding results

No	Sample	Size OD x Thickness (mm)	Average Expanding Percentage (%)
1	As cast	38 x 2.3	29
2	Drawn	30 x 1.85	31
3	Annealed	28 x 1.3	38
4	Planetary rolling	58 x 3	51
5	Extruded 1st	29 x 1.1	44
6	Extruded 2nd	24 x 1	46

The above table shows the variations of mechanical properties of different samples. The reason for this is different manufacturing processes applied to each tube. By comparison it can be seen that the samples, which have been planetary rolled, have a higher expanding percentage than cast or extruded tube samples. During the planetary rolling process, mechanical working greatly deforms the material. This deformation generates lots of energy which heats the material hot enough for full recrystallization of the grains to occur. That is why tubes produced by the planetary rolling process have better expanding percentage. It was also observed that the expanding percentage of the annealed samples was better than cast tube samples. The reason for this is because during the annealing process, the cast samples were heated to the recrystallization temperature, which was about half the melting point. In the new structure dislocation density has reduced and eliminated. So the grains within the structure recrystalize into many fine grains. Extruding is highly mechanical deforming process that can alter the grain size and orientation can substantially reduce the grain.

4. CONCLUSIONS AND FUTURE WORK

In this study, drift expanding analysis carried out on various copper tube samples comparison between as cast, drawing, annealing, planetary rolling and extrusion. From the above results, it can be concluded that:

1. The average expanding percentage for different tubes may also vary, depending on the manufacturing process.
2. Planetary rolling has a better expanding percentage than cast or extruded tube samples.
3. The continuous casting process of Cu is cheaper than thermo-mechanical processes, but the mechanical properties of components produced by continuous casting are lower than those produced by thermo-mechanical processes. So, in continuous casting process further downstream processes should be used to improve the mechanical properties of as cast rod. As for future work, this research can be extended by this investigation.

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