University of
Biskra

Mohamed Khider University of Biskra
Faculty of Science and Technology
Department of Mechanical Engineering

MASTER DISSERTATION

Domain: Science and Technology

Branch: Metallurgy

Specialty: Metallurgy

Ref:

Presented and supported by:

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25 juin 2024

Fabrication a setup for a continuous casting of metallic materials

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University year: 2023 – 2024

DEDICATION

In the beginning, I want to thank Allah for giving me the strength and courage to lead this modest work.

To my parents

I dedicate this dissertation to my loved parents who have always teach me to trust in Allah, believe in hard work and teach me that so much could be done with little.

To my sister and brother

Thank you for your everlasting love and warm encouragement throughout my research.

I want to thank everyone who helped me out on my journey.

ACKNOWLEDGEMENTS

- Initially, I would like to thank Almighty Allah for providing me with the courage to finish my dissertation.

- I would especially want to thank Pr. Zakaria BOUMERZOUG, my supervisor, who suggested this research topic to me and who has inspired me with his support, counsel, and worldwide perspective in this field.

- I express my gratitude to the jury members, Drs. Salim MESSAOUDI and Karima OUANES, who agreed to evaluate my research.

- I would like to thank Dr Mounir DJELLAB for helping me with the chemical reagent.

- I want to express my gratitude to Mr. Walid SEDRATI and all the engineers in the technology lobby for helping me in manufacturing some parts related to my project.

- I thank all those responsible for the metallurgical laboratory for the facilities and assistance.

- Finally, I thank all those who have supported me in this work, and thank my friends for all the support they have given me.

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General introduction

Continuous casting is a process whereby molten metal is solidified into a semi-finished billet, bloom, slab, or rod for subsequent rolling orwiredrawing processes.It is the most frequently used process to cast not only steel, but also aluminum and copper alloys. Since its widespread introduction for steel in the 1950s, it has evolved to achieve improved yield, quality, productivity, and cost efficiency. It allows lower-cost production of metal sections with better quality, due to the inherently lower costs of continuous, standardized production of a product, as well as providing increased control over the process through automation. Nevertheless, challenges remain and new ones appear, as methods are sought to minimize casting defects and to cast alloys that could originally only be cast via other means.

To carry out continuous casting, a continuous casting machine is essential for manufacturing a specific shape of metallic materials such as rod , wires ec... Continuous casting machines are complex industrial systems designed to carry out the continuous casting process efficiently. There are various types of continuous casting machines, each tailored to specific metal production needs. Like the vertical downward continuous casting machine which will be my focus in this dissertation work.

The main objective of my dissertation is realizing a small vertical downward continuous casting machine with a melting furnace work by induction heating. This present work is based on the last machine manufactured the previous year.

The dissertation is divided into three chapters:

- The first chapter describes the various continuous casting process types as well as the various machine types and their uses.
- The second chapter is devoted to a bibliographic research on the vertical downward continuous casting process, and the different parameters of it.
- The third chapter is reserved for the description of the manufactured continuous casting machine and the operation of the continuous casting machine manufactured in our laboratory with the presentation of some manufactured samples.

Chapter I:
Continuous casting process

Chapter I: Continuous Casting Process

Introduction and scope:

Continuous casting is the important linking process between steelmaking and rolling. As early as 1856, Henry Bessemer suggested a continuous casting method butjust during the 1930s and 1940s continuous casting became a common productionmethod for nonferrous metalsand later from the 1960s for steels. The relatively low thermal conductivity of steel and the high casting temperatures meant that many problemshad to be solved compared to nonferrous casting. In the mid-1980s, continuous castinggrew into the biggest casting method, exceeding the conventional ingot steel castingroute. In the ingot casting route, individual molds are filled with molten steel to producesteel ingots. The continuous casting method has a lot of benefits compared to the olderingot casting methods. The major advantages are improvement of steel quality, betteryield, and savings of energy and manpower. Today, about 95% of the world’s steel production is made by continuous casting and a great number of steel qualities are cast in verywide variety of dimensions.

Therefore, this chapter will be related to continuous casting process, types, and applications.

1. Principle of continuous casting process:

The principle of the continuous casting method is presented in **FigureI.1**. The liquid steel in a ladle is transferred to the casting machine. When the casting operation starts, the-nozzle at the bottom of the ladle is opened and the steel flows at a controlled rate into the-tundish and from the tundish through a submerged entry nozzle into one mold orseveral molds. The molds are generally water-cooled copper molds. The first solidification takes place at the metal/mold interface. The thickness of the solidified shell increases progressively when it is withdrawn through the machine. At the mold exit, the shell must be thick enough to support the liquid pool. Below the mold, the shell is cooled byspraying water. The mold cooling is called the primary cooling and the spray coolingthe secondary cooling. At the machine end, the strand is cut off and transferred to a rolling mill **[1].**

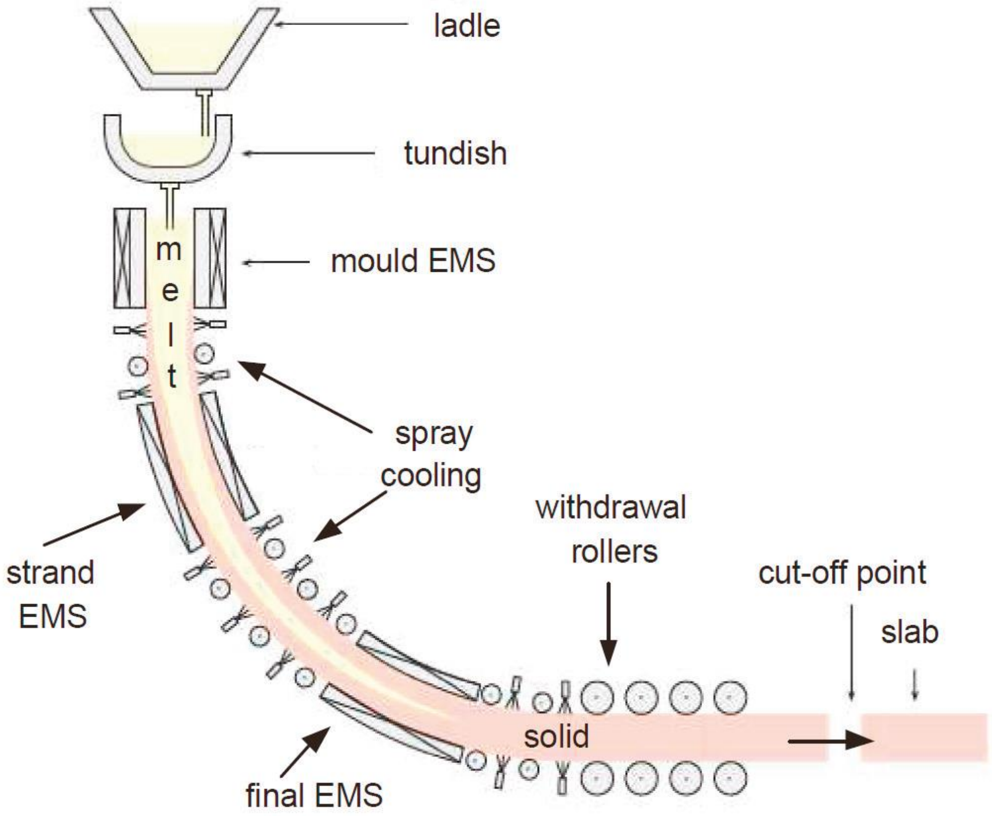


Figure I.1: Schematic for the continuous casting of steel **[2].**

2. Types of continuous casting:

There are three types of continuous casting process: horizontal continuous casting, vertical downward continuous casting and vertical upward continuous casting.

2.1. Vertical continuous casting (VCC):

As mentioned above, there are two procedures involved in vertical continuous casting: vertical upward continuous casting and vertical downward continuous casting.

2.1.1. Vertical upward continuous casting (VUCC):

Vertical upward continuous casting is a method used in metallurgy and materials processing to produce long lengths of metal with a consistent cross-sectional shape. This process is commonly employed for casting metals such as steel, aluminum, and copper. The key characteristic of vertical upward continuous casting is that the metal solidifies while moving upward against the force of gravity.

In VUCC the molten metal is fed vertically and the metal flow is upward (**Fig. I.2**), the casting nozzle is situated beneath the two rolls. By the metallostatic pressure, determined from the level of liquid in the tundish, the molten metal flows through the nozzle and immediately into contact with the rolls. The rolls transport the solidified material in such a way, that the material gets a light deformation **[3].**

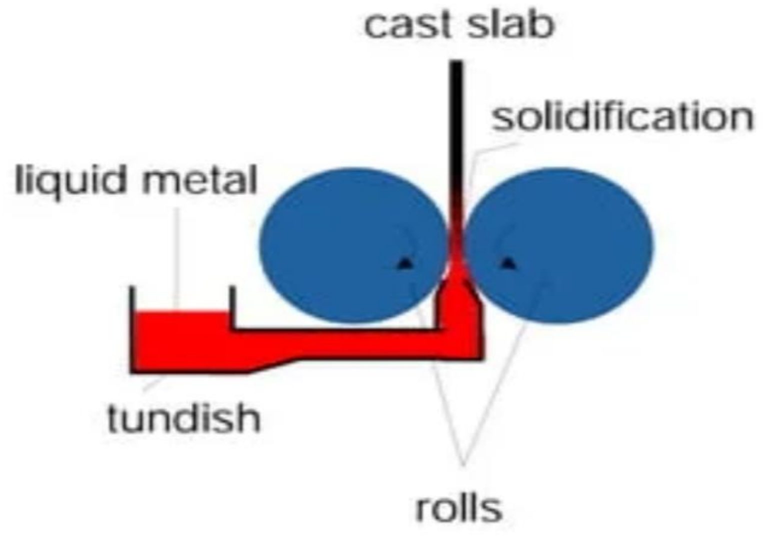


Figure I.2: Schematic diagram of the vertical downward continuous casting **[3].**

The main advantage of this casting method is the simultaneous operation of several moulds(crystallizers) immersed in liquid metal and the possibility to stop easily each of them while the rest of the moulds continue their function. Another advantage of the upwards continuous casting is the absence of a tundish **[4].**

An industrial vertical upward continuous casting machine is shown in figure I.3. It is a type of machinery intended specifically for the synthesis alloy materials, including pure copper and aluminum alloys.

FigureI.3: Industrial vertical upward continuous casting machine **[5].**

2.1.2. Vertical downward continuous casting (VDCC):

In VDCC the molten metal is fed vertically too, but with one difference: the metal flow is downward. The VDCC process is used to overcome a number of ingot-related difficulties such as piping, mold spatter, entrapped slag, and structure variation along the length of the product. It is used to produce blooms, billets, slabs and tubing directly from the molten metal. In this process, molten metal flows into a refractory-lined intermediate pouring vessel, where impurities are skimmed off **[6]**. From there, the metal travels through a bottomless water-cooled copper mold in the form of a vertical tube open at both ends andbegins to solidify as it travels downward along a path supported by rollers **[7]**. A schematicsketchof the continuous casting process is shown below in FigureI.4.

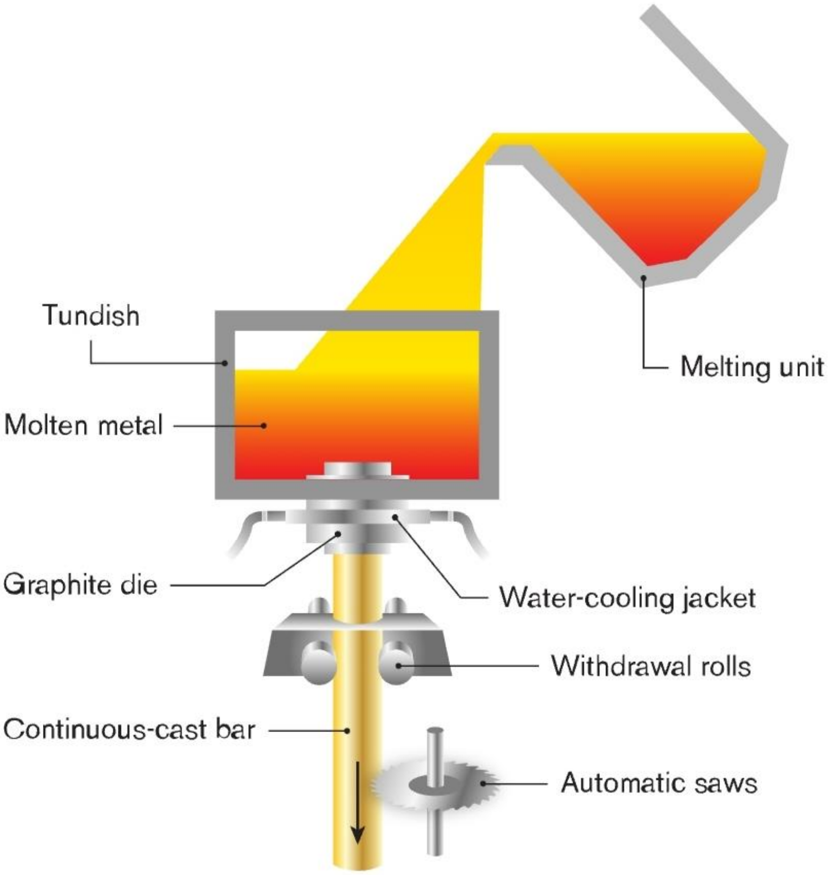


Figure I.4: Schematic sketchof vertical downward continuous casting process.**[8]**

A part of an industrial vertical downward continuous casting machine is depicted in figure I.5.

FigureI.5: Part of an industrial vertical downward continuous casting machine. **[9]**

2.2. Horizontal continuous casting (HCC):

Horizontal continuous casting (HCC) has been widely employed in casting of nonferrous metal wires such as aluminum, magnesium, zinc, copper and their alloys due to itscharacteristic superiorities which includes low investment cost, low energy consumption, high efficiency and high surface quality. Continuous extrusion forming processwaswidely used in the efficient continuous production of Al alloys andother metals. This process owns the advantages of saving energy, high extrusion ratio and production efficiency, superiors in lengthand homogeneity of the production and so on. Variety forms ofproducts including tubes, solids, complex profiles and coaxialproducts can be produced by the conform process **[10].**

The HCC equipment is presented in Figure I.6 and operates as follows:

First, the metal is molten in the melting furnace and tapped into the ladle for transportation to the casting furnace or given directly into the tundish of the casting furnace. From the tundish the hot metal flows under the influence of gravitation trough the graphite mold, installed in the crystallizer horizontally, where metal is being cooled and gains definite form. The roll supports catches up the product and adjusts the casting speed. The product comes out of the casting machine horizontally. With a moving circular saw the product is being cut into predefined length and after that passed on for further processing **[11].**

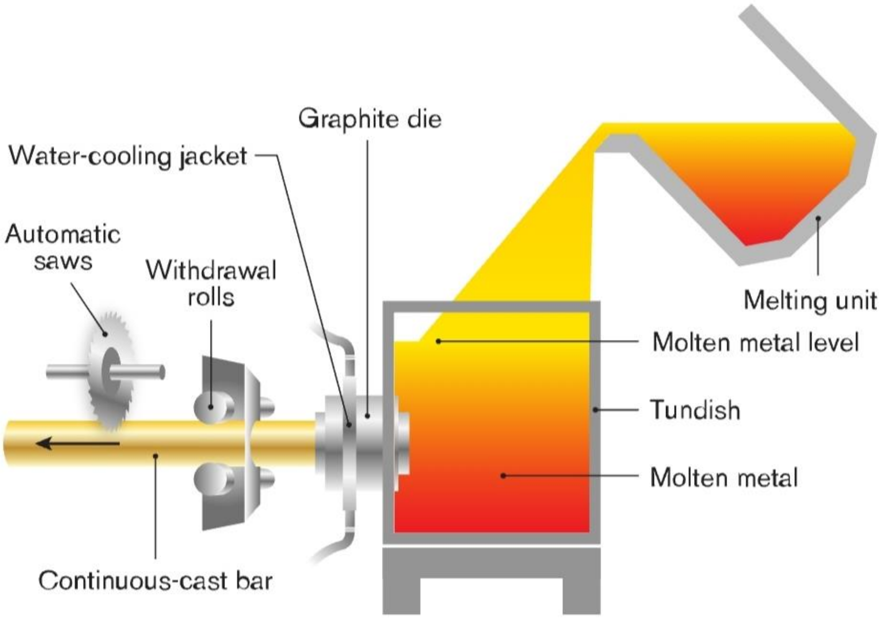
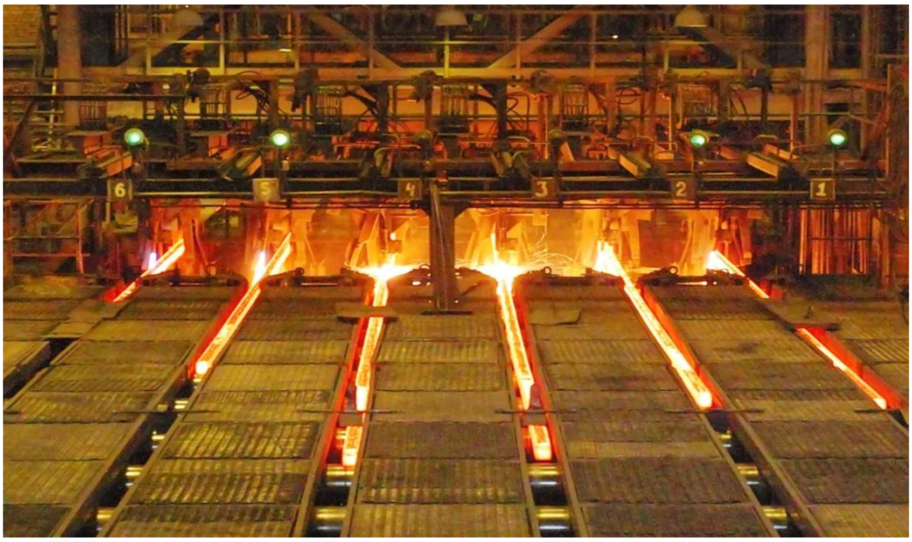


Figure I.6: Schematic sketch of horizontal continuous casting process.**[8]**

The HCC is considered the most common and most widely used in industry. Figure I.7 shows a part of this industrial process.



FigureI.7: Part of an industrial horizontal continuous casting machine**[12]**.

3. Industrial applications of continuous casting:

Continuous casting is an industrial process which is widely used innumerous applications, primarily in the production of metals and alloys. Here are some key industrial applications of continuous casting:

Steel Production:

. Continuous casting is extensively used in the steel industry to produce long and continuous strands of steel, known as billets, blooms, or slabs.

. It enables the efficient production of semi-finished steel products with consistent cross-sectional dimensions, reducing the need for subsequent shaping processes.

Aluminum Production:

. Continuous casting is employed in the aluminum industry to produce aluminum billets and slabs.

. The process allows for the production of high-quality aluminum products with improved mechanical properties.

Copper and Copper Alloys:

. Continuous casting is utilized in the production of copper and various copper alloys, such as brass and bronze.

. The process is particularly advantageous for the production of long and continuous copper rods and tubes.

Lead and Tin Alloys:

. Continuous casting is applied in the production of lead and tin alloys, which find use in various applications, including bearings and soldering materials.

Zinc Alloys:

. Continuous casting is used for certain zinc alloy production, such as zinc-aluminum alloys.

Specialty Alloys:

. The process is employed for producing specialty alloys with specific properties, such as high-temperature alloys and nickel-based superalloys.

Continuous Casting of Titanium:

. In the aerospace and medical industries, continuous casting is used for titanium and titanium alloy production, providing high-strength materials for critical applications.

Magnesium Alloys:

. Continuous casting is used for certain magnesium alloys, contributing to the production of lightweight materials with improved strength.

Shape Casting of Non-ferrous Metals:

. Continuous casting is employed in the production of various non-ferrous metal shapes, including rods, tubes, and profiles.

It is important to note that that in continuous casting, the terms "billet," "bloom," and "slab" refer to different types of semi-finished steel products with varying cross-sectional shapes and sizes. These products serve as the starting material for further processing and manufacturing of various end products. Here's an overview of each: (Fig. I.8)

Billet:

. A billet is a semi-finished steel product that typically has a square or rectangular cross-section. Billets are often smaller in size compared to blooms and slabs.

. Billets are commonly used as feedstock for the production of bars, rods, and wire. They undergo further processing, such as hot rolling or extrusion, to achieve the desired final dimensions and properties.

Bloom:

. A bloom is a larger semi-finished steel product with a square or rectangular cross-section, larger than a billet.

. Blooms are often used for the production of structural shapes, such as I-beams and T-sections. They are also processed into other products like seamless tubes and large-diameter pipes.

Slab:

. A slab is a flat and broad semi-finished steel product with a rectangular cross-section. Slabs are larger than both billets and blooms.

. Slabs are primarily used for the production of flat-rolled products, such as sheets, plates, and coils. They undergo further processing in rolling mills to achieve the desired thickness and shape.

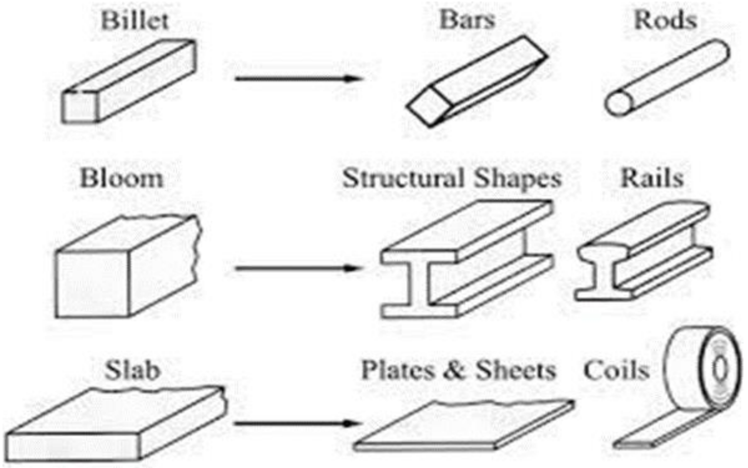


Figure I.8: Schematic sketches illustratethe difference between bloom, slab, and billet. **[13]**

4. Advantage and disadvantage of continuous casting:

4.1. Advantages of continuous casting:

Continuous casting has many advantages. For starters, with other casting methods, it is difficult to cast metal into long, tubular forms. With continuous casting, you can make long tubes in a variety of shapes and sizes. Here are some of the other advantages to consider:

Continuous castings are perfect for pressure applications. They are consistently homogeneous and dense.

. Less machining stock is needed.

. Less material is wasted than some other casting methods.

. These castings are straight and concentric, meaning there is no deviation. You get the same product every time.

. Suppliers often maintain stock of standard products, available to distributors on demand.

. Cost advantages can be offered for standard shapes and sizes.

4.2. Disadvantages of continuous casting:

. There are a few limitations to consider when looking at continuous casting. The biggest is the cost of setup. Due to both the high cost of creating a mold and the time spent setting up the machine for each project; it is not practical to use this method for small quantities or for special shapes of a product. It also isn't economical to use this method with special metal alloys in smaller quantities.

.Another thing to consider is the shapes that can be cast. Continuous casting is limited to more simple shapes that have a stable cross-section. This method is not a good option for some of the more tedious, difficult casting projects.

Partial conclusion and outlook:

From the contents of this chapter, three different types of continuous casting exist in the industry, and for each type, there is the specific continuous casting machine. Each machine has its own configuration and produces specific materials like wires, rods etc. ....

References

[1] S. Louhenkilpi. Continuous Casting of Steel, Department of Materials Science and Engineering, Aalto University School of Chemical Technology. Espoo, Finland, pp 373-434. 2014.

[2] M. Vynnycky, Continuous Casting, Printed Edition of the Special Issue Published in Metals, UniversityofLimerick ,Ireland. 2019

[3] Vertical upward continuous casting from https://www.slideshare.net/corematerials/talat-lecture-3210-continuous-casting Download on 17/11/2023

[4] K. M. Mihovsky, B. Viktor, Hadzhiyski, Rositsa V. Gavrilova. New mould with combined: Indirect and direct cooling, for vertical upwards continuous casting of aluminium wires. University of Chemical Technology and Metallurgy, Sofia, Bulgaria. Vol. 10, No 2, pp. 117–124. 2010 .

[5] Industrial vertical up ward continuous casting machine from https://www.rautomead.com/equipment. download on 08/11/2023

[6] H.F. Schrewe, Continuous Casting of Steel, Fundamental Principles and Practice,Stahl und Eisen, Dusseldorf, Germany, 1991.

[7] T.R.Vijayaram. Metallurgy of Continuous Casting Technology, International Journal of Manufacturing & Industrial Engineering – IJMIE. pp. 1589 – 2374. 2014.

[8] Schematic sketch of vertical downward continuous casting process from https://www.concast.com/production.php. Download on 01/11/2023

[9] Part of an industrial vertical downward continuous casting machine from https://aisusteel.org/en/6203/ download on 18 November 2023.

[10] X. Ji, H. Zhang, S. Luo, F. Jiang, D. Fu. Microstructures and properties of Al–Mg–SI alloy overhead conductor by horizontal continuous casting and continuous extrusion forming process, Materials Science & Engineering. pp. 129 – 134. 2015.

[11] Horizontal continuous casting process from https://kmmbronze.com/technologies-of-continuous-casting-horizontal-vertical-downward-. Download on 10/11/2023

[12] Part of an industrial horizontal continuous casting machine from https://www.linkedin.com/pulse/introduction-continuous-casting-machine-daisy-electric-arc-furnace download on 07/11/2023

[13] A schematic sketch illustrate the difference between bloom, slab, and billet from https://clasicosautomocion.blogspot.com/2013/01/operaciones-de-conformado-de-metales.html Download on 03/11/2023.

Chapter II:

Vertical downward continuous casting

Chapter II: Vertical downward continuous casting

Introduction:

In this chapter, more details about the vertical downward continuous casting process (VDCC) will be presented. In addition, this chapter is devoted to a bibliographic research on the VDCC process, and the different parameters of it.

1. Presentation of vertical downward continuous casting:

In the vertical downward continuous castingprocess (Fig.II.1), the molten metal in a ladle is transferred to the casting machine. When the casting operation starts, the nozzle at the bottom of the ladle is opened and the liquid metalflows at a controlled rate into thetundish and from the tundish through a submerged entry nozzle (SEN) into one mold or several molds. The molds are generally water-cooled copper molds. The first solidification takes place at the metal/mold interface. The thickness of the solidified shell increases progressively when it is withdrawn through the machine. At the mold exit, the shell must be thick enough to support the liquid pool. Below the mold, the shell is cooled by spraying water. The mold cooling is called the primary cooling and the spray cooling the secondary cooling. At the machine end, the strand is cut off and transferred to a rolling mill **[1].**

An industrialvertical downward continuous casting machine is presented in figure II.2.

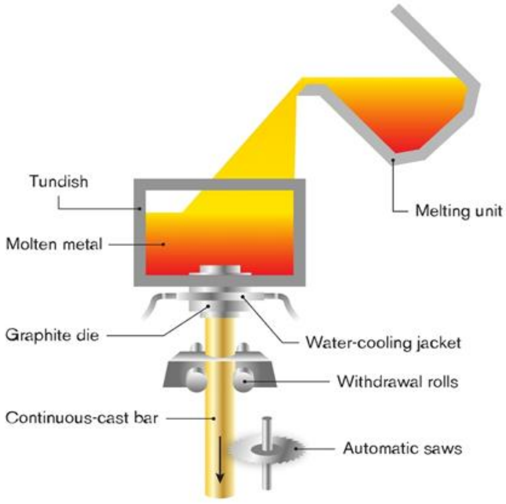


Figure II.1: Representative diagram of the VDCC machine **[2].**

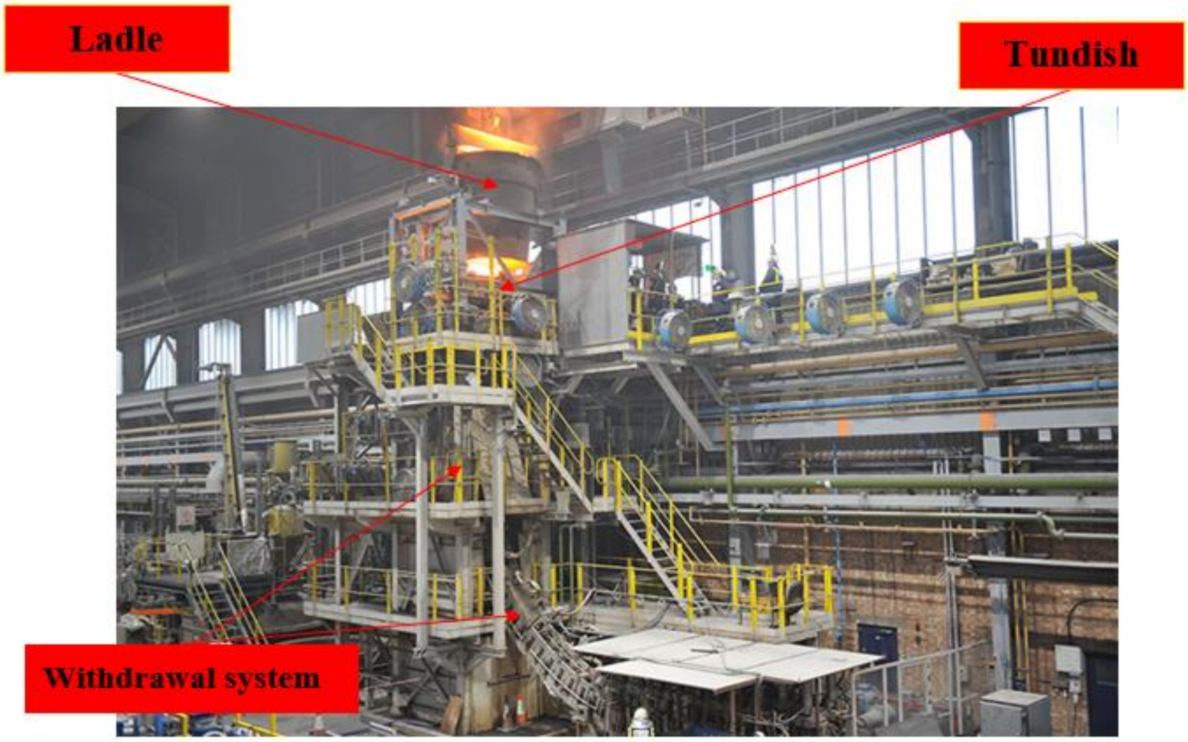


Figure II.2: Vertical downward continuous casting machine **[3].**

2. Equipment and components:

Different parts and components are involved in the vertical downward continuous casting process. Here are some key elements:

1. Ladle
2. Tundish
3. Mold
4. Withdrawal system
5. Secondary Cooling Zone
6. Cutting Equipment

2.1. The ladle:

A ladle in continuous casting (Figure II.3**)** is a refractory-lined container used to transport and pour molten metal into the tundish. It plays a crucial role in maintaining a continuous flow of metal during the casting process, ensuring a smooth and controlled feed into the tundish to produce quality cast products. Ladles are designed to withstand high temperatures and are often equipped with mechanisms for precise pouring to achieve uniform casting.

Figure II.3: A ladle for continuous casting **[4].**

2.2. The tundish:

The tundish is a reservoir designed in a manner to maintain a constant flow rate withoutany impediment during flying ladle change over for the course of continuous casting process **[1].**The main function of a tundish (FigII.4.a) is to distribute the molten metal over the number of casting strands and to provide a more constant head to help in the control of pouring the liquid metal into the continuous casting mold. The tundish feeds the molten metal to casting machine (mold), hence act as a buffer vessel between the ladle and the mold. It also serves the purpose of controlling metal flow to the mold and metal cleaning. From thetundish, molten metal is poured into the top of an open-base copper mold through submerged entry nozzle **[5].** Figure II.4.b shows the picture of the tundish at steel company.

Figure II.4: **(a)**Diagram of continuous casting process**(b)**The 4-strand tundish at Millcon Steel PLC, Thailand **[6].**

2.3. The mold:

In the continuous casting process, liquid metal flows from a ladle, through a tundish into the mold. The mold is regarded as the heart of the continuous casting process and plays a very important role in the efficiency of the process and the strand quality. It is in the mold that the final cast shape and the strand surface quality are produced. If the conditions are not correct in the mold, then the strand quality cannot be corrected later. Once in the mold, the liquid metal freezes against the walls of the water-cooled copper mold to form a solid shell. Mold is basically an open-ended box structure containing a water-cooled inner lining fabricated from a high purity copper alloy. The box can come in many shapes and sizes in order to cast different semis such as blooms, billets, round beam blanks, slabs, and thin slabs.

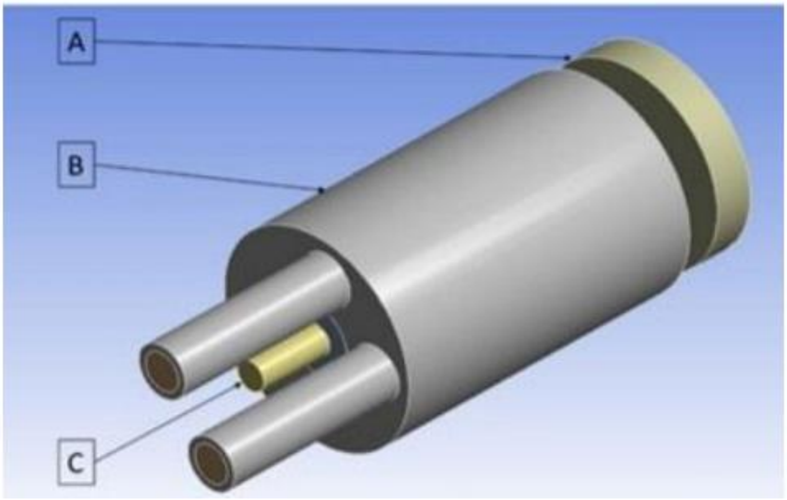


Figure II.5: A general view of a simulation mold(crystallization

System); (A)–a graphite crystallizer, (B)–a copper cooling system, (C)–a copper cast rod **[7].**

2.4. Withdrawal system:

The withdrawal system in continuous casting refers to the set of mechanical and operational components designed to gradually extract the solidifying metal product from the casting mold in a continuous and controlled manner. This system is a crucial element in the continuous casting process, where molten metal is continuously transformed into a solid shape with a consistent cross-section, such as slabs, billets, or rods.

The withdrawal system includes variouscomponents and mechanisms, such as withdrawal rolls, withdrawal straighteners, mold oscillation devices, and control systems (Fig.II.6). Its primary objectives are to regulate the speed at which the metal solidifies, ensure uniform cooling and solidification, and maintain the desired dimensions and quality of the final cast product. The withdrawal system plays a pivotal role in the overall efficiency and effectiveness of continuous casting operations in metallurgical processes.

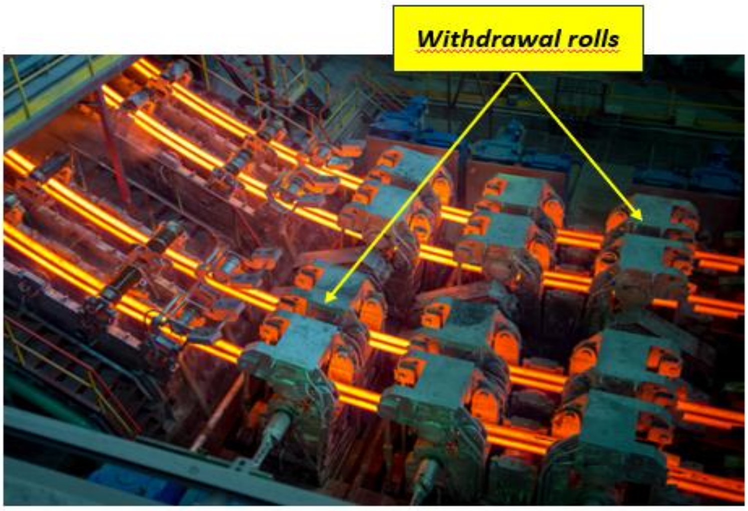


Figure II.6: Withdrawal system for a vertical downward continuous casting **[8].**

2.5. Secondary Cooling Zone:

The solidifying metalis withdrawn at the casting speed from the mould by means of withdrawal rollers (Fig.II.7). Below the mould, water sprays are used to cool down the strand. This area is known as the secondary cooling zone and is usually split upinto zones of sprays, with each spray zone waterflux individually controlled. The strand is alsosupported by means of rollers. Once the strandexits the water spray or secondary cooling zone itcools off in air after which it is cut and sent forfurther processing **[9].**

The secondary cooling zone is a critical part of the overall continuous casting system, contributing significantly to the quality, consistency, and efficiency of the cast metal products. It allows for the customization of the casting process to meet the specific requirements of different alloys and product specifications.

Figure II.7: The secondary cooling **[10].**

2.6. Cutting Equipment:

The cutting process is a crucial step in the production of metal products with specific dimensions and lengths. Various cutting methods and equipment are employed depending on the type of metal, the product requirements, and the casting process used. Here are some common cutting equipment and methods in continuous casting:

- Torch Cutting
- Flame Cutting Machines
- Plasma Cutting
- Water Jet Cutting

- Saw Cutting

The choice of cutting equipment depends on factors such as the type of metal, the thickness of the cast product, production volume, and the required precision. Automated cutting systems are often integrated into the continuous casting line to ensure efficiency and consistency in the production process.

It is important to notify that the specific design and configuration of the fundamental components involved in vertical downward continuous casting can vary depending on the type of metal being cast and the desired final product.

3. Continuous casting parameters:

Continuous casting is a complex process, and several parameters need to be carefully controlled to ensure the production of high-quality metal products. The specific parameters can vary depending on the type of metal being cast, but here are some common continuous casting parameters:

- Casting speed
- Cooling rate
- Melt temperature (casting temperature)
- Mold level

3.1. Casting speed:

For a particular strip entry thickness, casting speed is one of the key factors influencing the metallurgical quality of the cast product. A decent strip quality can be produced within a certain casting speed range. Low casting speed can lead to the metal in the nozzle tip freezing too soon, which increases the rolling stress and causes hot cracking and macro segregation. While productivity is increased at faster speeds, there is a chance that a semisolid zone will form at the exit center of the strip as the liquid metal sump is moved closer to the roll exit.

3.2. Cooling rate:

The cooling rate during this process significantly influences the microstructure, mechanical properties, and overall quality of the final metal product. Here's a brief description of the importance of cooling rate in continuous casting:

Solidification Control: Cooling rate directly affects the solidification of molten metal. A controlled and optimized cooling rate is essential to achieve uniform and fine-grained solidification throughout the cast product.

Microstructure Formation: The rate at which the metal cools influences the formation of its microstructure. A slower cooling rate generally promotes the growth of larger grains, while a faster rate results in finer grains. The desired microstructure depends on the specific properties required for the final product, such as strength, toughness, and ductility.

Homogeneity of Properties: Consistent and controlled cooling rates contribute to the homogeneity of mechanical and metallurgical properties across the entire cross-section of the cast product. This is crucial for ensuring that the material meets specified standards and performance criteria.

Reducing Defects: Proper cooling rates help in minimizing defects like hot tears, cracks, and porosity in the final product. By carefully controlling the cooling process, manufacturers can reduce the likelihood of defects that could compromise the integrity of the cast metal.

3.3. Melt temperature (casting temperature):

The melt temperature, or the temperature of the molten metal before casting, significantly impacts the quality, efficiency, and feasibility of the casting process. Higher melt temperatures lead to better mold filling, while lower temperatures slow down the solidification process, potentially affecting the final product's properties. The temperature also impacts energy consumption, affecting the overall energy consumption of the process. The metallurgical properties of the cast metal, such as grain size and microstructure, are also affected by the melt temperature. Balancing the melt temperature is crucial for minimizing defects, ensuring casting speed, and minimizing equipment wear and maintenance. Therefore, controlling the melt temperature is vital for achieving the desired metallurgical properties in the final product.

3.4. Mold level:

The mold level in continuous casting is a crucial parameter that influences the quality, efficiency, and success of the casting process. It determines the initial height of the molten metal in the mold, affecting mold filling and shape. The mold level also affects the shape and stability of the meniscus, which is the interface between the metal and the mold. A higher mold level leads to a faster solidification process, affecting the microstructure and mechanical properties of the final product. Improper mold level control can lead to hot tearing and surface quality issues. Proper mold level adjustment allows for optimal casting speeds, balancing efficiency with quality and defect prevention. It also affects mold wear and maintenance, energy consumption, and product quality. Therefore, precise mold level control is essential for producing homogeneous, dimensionally accurate, and defect-free metal products.

Optimizing these parameters is essential for achieving high-quality continuous castings with minimal defects and consistent mechanical properties. The specific parameters may vary depending on the type of metal being cast and the desired final product. Continuous casting technology is continually evolving, and researchers and engineers work to refine and improve these parameters for better efficiency and product quality.

4. Case studies:

In this part, some previous researches conducted on vertical downward continuous casting process are presented according to the effect of parameters on the final product.

4.1. Effect of casting speed:

Bell et al. **[11]** investigated the influence of casting speed on the structure andmechanical properties of continuous cast DHP copper tube. 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 presents the copper tube samples tested in this study.

Table 1: The Copper tube samples tested in this research **[11].**

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

Symbols, designation and units for the driftexpanding test of tubes are presented in Table 1 and shown in Fig.8. Fig.9 (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.

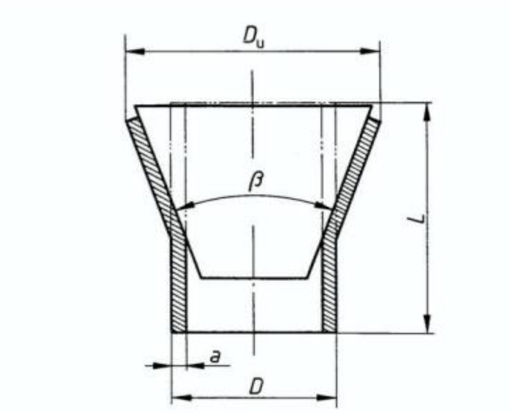


Figure II.8: Designation of the drift-expanding test of tubes **[11].**

Table 2: Symbols, Designation and Units for the drift-expanding test of tubes **[11].**

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 II.9: drift expanding procedure **[11].**

Average Expanding Percentage:

The results of average expanding percentage of copper tube samples are presented in Fig II.9.

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 **[11].**

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 %

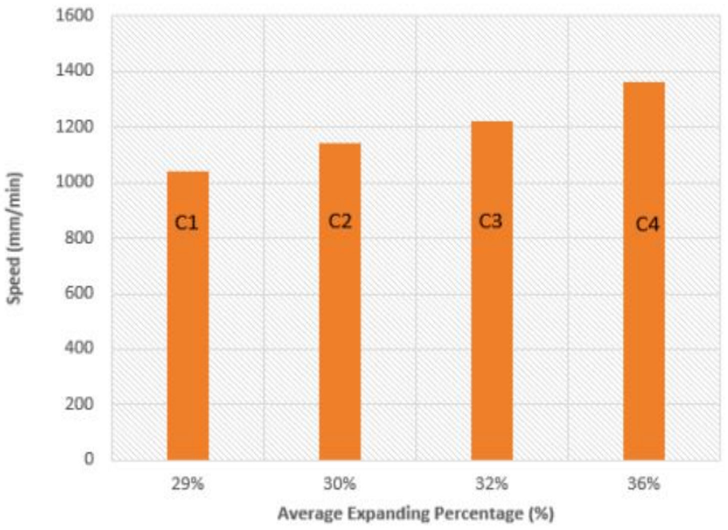
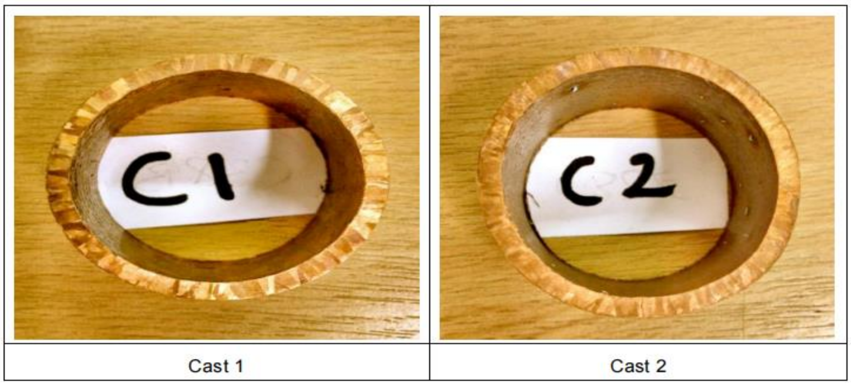


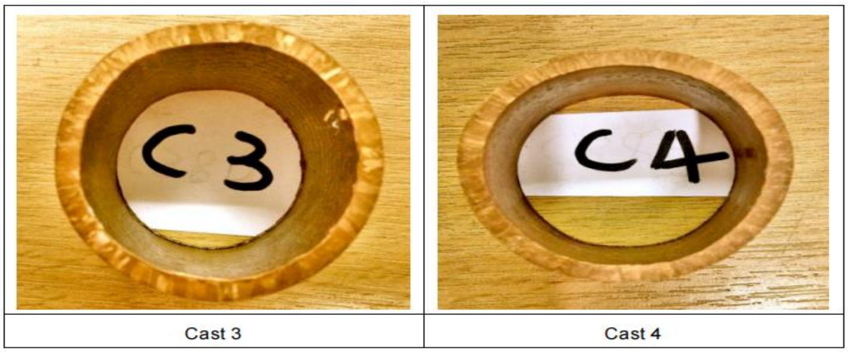
Figure II.10: Comparison average expanding percentage of copper tube samples**[11].**

Grain Structure:

The effect of casting speed on the structure of the continuous cast DHP copper tube is illustrate in FigII.11. 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 FigII.11.



Cast 1 Cast 2



Cast 3 Cast 4

Figure II.11: Comparison grain structure of copper tube samples**[11].**

To enhance a material's mechanical properties, reduce grain size or increase grain boundaries. This is achieved by increasing casting speed, which leads to a higher number of columnar grains and a greater ratio of grain boundaries to dislocations. This results in a structure with finer grains due to a thermal change in the material's transition from liquid to solid.

From the above experimental results, some important conclusions have been drawn:

- 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.
- 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.

4.2. Effect of temperature:

Bagherian et al. **[12]** examined the effect of temperature on tensile strength, elongation percentage, and microstructure of continuous cast copper alloys. They found the following results:

The microstructure of the copper wire is affected by the melting temperature as it is shown in figure II.8. Concerning the mechanical properties, the tensile strength has been examined and it was found that strength of oxy gen free continuous cast copper (OFCu) has changed when changing the melt temperature. It can be seen that the tensile strength drops to 169.56MPa from 183.14 when the melt temperature is increased from 1097℃ to 1140℃ (Fig.II.13). In addition, the elongations of these samples are increased by 33%, 35%, 36% and 37% respectively, when the melt temperature is increased from 1097 to 1140 ℃. In summary, the mechanical properties of continuous cast oxygen free copper (OFCu) can be changed by increasing the melt temperature. The reason is because the melt temperature is one of the most important factors affecting the size of atomic clusters, as the temperature changes can Influence the nucleation. In the other side, according to the relationship between the grain growth rate and degree of super-cooling, the larger the degree of super cooling is the faster grain growth rate. So, with the increase of degree of sup super cooling is the faster grain growth rate. So, with the increase of degree super-cooling the grain size is decreased which then results in increasing elongation percentage**[13, 14].**

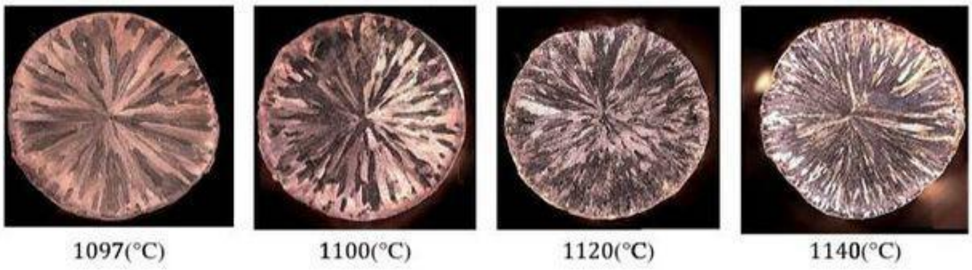


Figure II.12: Grain structure in cast OFCu samples **[12].**

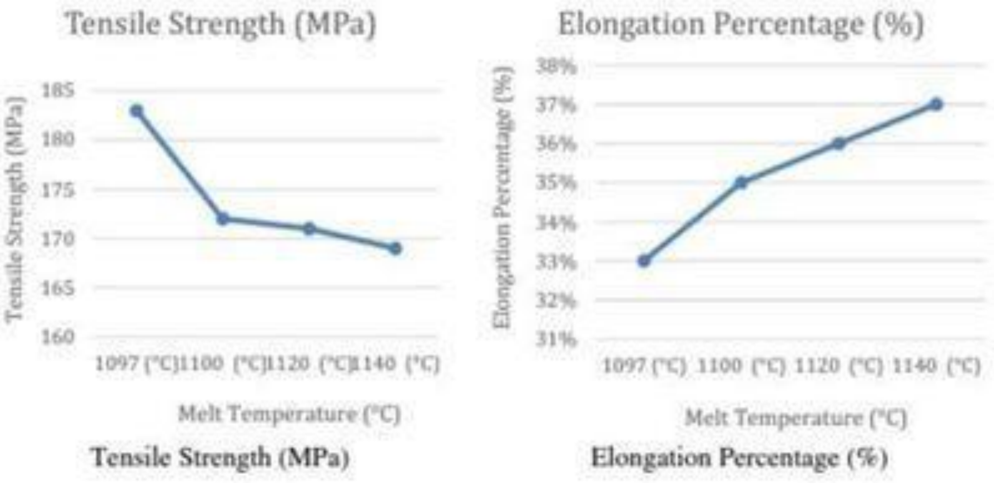
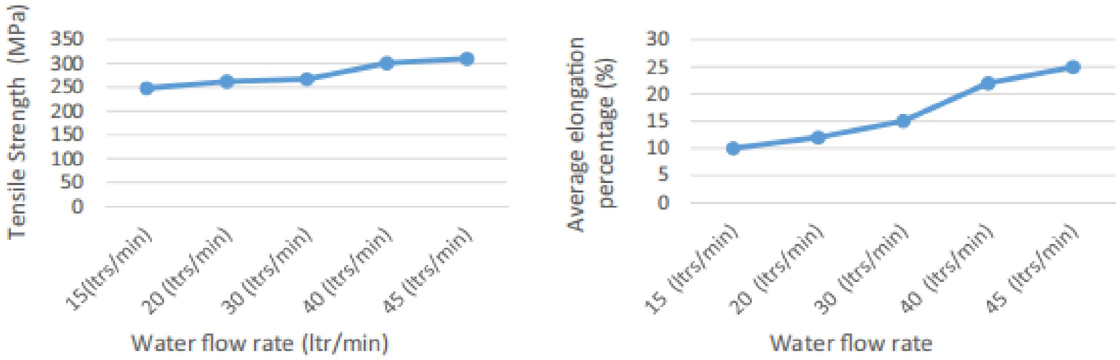


Figure II.13: Tensile strength and elongation percentage of OFCu samples**[12].**

4.3. Effect of Water flow rate:

The objective of this section was to present a previous research works **[15, 16]** related to the effect of water flow rate on the mechanical properties of continuous cast copper rod by varying water flow rates. After cooling experiments the tensile strength has been examined and it was found that increase in water flow rate affects the tensile strength and elongation percentage. The results of average elongation percentage of copper alloy samples are presented in Figure II.14. Table II.4 shows the tensile strength and average elongation percentage of the continuous cast copper rod samples, It can be seen that sample 1 has the higher elongation percentage. So the water flow rate could improve the elongation percentage of samples from 10% to 25%. In continuous casting process water is used to cool the mold in the initial stages of solidification. So water flow rate in continuous casting plays a key role in transforming heat from the mold and solidifying metal during the continuous casting of copper alloys. It has also been previously reported that, water flow rate is one of the main process parameters that can change upon direct chill casting. Because increasing the water flow in the mould increases the heat- transfer rate and thereby decreases the mould temperature **[15, 16].**



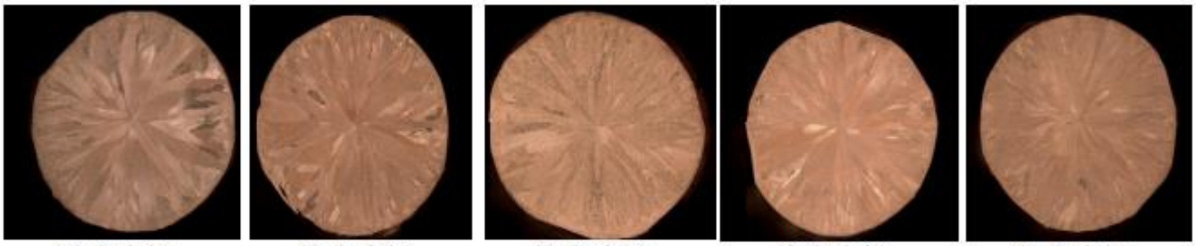
Tensile strength

Elongation percentage

Figure II.14: Tensile strength and elongation percentage of CuSnP samples**[12].**

Table 4: Average elongation percentage of CuSnP samples**[12].**

Sample	Rod dia (mm)	Die	Pull distance (mm)	Pull dwell (s)	Acceleration (s)	Deceleration (s)	Casting speed (mm/min)	Water flow rate (l/min)	Tensile strength (MPa)	Average elongation Percentag (%)
Cast 1	8	Graphite	10	0	0.02	0.02	3500	15	310	10
Cast 2	8	Graphite	10	0	0.02	0.02	3500	20	301	12
Cast 3	8	Graphite	10	0	0.02	0.02	3500	30	267	15
Cast 4	8	Graphite	10	0	0.02	0.02	3500	40	262	22
Cast 5	8	Graphite	10	0	0.02	0.02	3500	45	248	25



15 (ltrs/min) 20 (ltrs/min) 30 (ltrs/min) 40 (ltrs/min) 45 (ltrs/min)

Figure II.15: Comparison grain structure of CuSnP samples**[12].**

Partial Conclusion:

It can be concluded from this chapter that the vertical downward continuous casting stands as a pivotal method in modern metal production, offering precise control over key parameters such as temperature, casting speed and cooling rate. Its significance lies in its ability to facilitate the efficient and high-quality production of metal products across diverse industries. By optimizing process parameters, manufacturers can enhance productivity, reduce costs, and ensure the integrity of the final products. As research and development continue to advance, vertical downward continuous casting remains poised to meet evolving industry demands for sustainable, reliable, and cost-effective metal production methods.

References

[1] S. Louhenkilpi. Continuous casting of steel, Department of Materials Science and Engineering, Aalto University School of Chemical Technology. Espoo, Finland, pp 373-434. 2014

[2] Representative diagram of the VDCC machine from https://www.concast.com/production.php. Download on 01/05/2024

[3] Vertical downward continuous casting machine from https://www.mpiuk.com/equipment-continuous-casting.htm download on 5/12/2023

[4] A ladle for continuous casting from https://ifglgroup.com/solution/iron-steel/continuous-casting/ladle download on 12/12/2023

[5] J. R. De Sousa Rocha, E. E. B. De Souza, F. Marcondes, and J. A. De Castro, "Modeling and computational simulation of fluid flow, heat transfer and inclusions trajectories in a tundish of a steel continuous casting machine," J. Mater. Res. Technol., vol.8, no.5, pp.4209–4220. Sep. 2019

[6] A. Harnsihacachaa , A. Piyapaneekoona , C. Wattanapornb , P. Kowitwarangkul. Flow prediction in the multi-strand continuous casting tundish of Millcon Steel PLC, The 10th Thailand International Metallurgy Conference (The 10th TIMETC). Proceedings 5 pp 9229–9237. 2018

[7] External Surface Quality of the Graphite Crystallizer as a Factor Influencing the-Temperature of the Continuous Casting Process of ETP Grade Copperhttps://www.mdpi.com/1996-1944/14/21/6309 Download on 20/01/2024

[8]Withdrawal system for a vertical downward continuous casting from https://www.syalons.com/2021/01/13/continuous-steel-casting-syalon/.Download on 01/05/2024

[9] F.R. Cal Uisani-Calzolari , LK. Craig , P.C. Pistorius. Speed Disturbance Compenation in the Secondary Cooling Zone in Continuous Casting, ISIJ International, Vol. 40 , No. 5, pp 469–477. 2000

[10] Secondary cooling zone from https://www.asenso.de/workshop-stranggiessen download on 26/12/2023

[11] E. Bagherian , C. Bell , M. Cooper , Y. Fan , B.A. Abdolvand. Influence Of Casting Speed On The Structure And MEechanical Properties Of Continuous cast DHP Copper Tube. 23rd International Conference on Metallurgy and Materials, Brno, Czech Republic. 2014

[12] E.R, Bagherian, Y, Fan, Mervyn Cooper,Brian Frame and Amin Abdolvand, Effect of melt temperature, cleanout cycle, continuous casting direction (horizontal/vertical) and super-cooler size on tensile strength, elongation percentage and microstructure of continuous cast copper alloys, School of Science and Engineering, University of Dundee, DD1 4HN Dundee, Scotland, UK, EDP Sciences, 2016.

[13]F. Liu, F. Sommer, C. Bos, E.J. Mittemeijer, Int. Mater. Rev. 52 193-212. 2007

[14]P, Lundkvist, Ironmak. Steelmak. Process, Prod. Appl. 41 304-309.2014

[15]Qing Liu, Control Technology of Solidification and Cooling in the Process of Continuous Casting of Steel, Science and Technology of Casting Processes, Published:
September 26. 2012

[16]J. Sengupta, Metall. Mater. Trans. *A* **36,** 187-204. 2005

Chapter III:

Manufacturing of Vertical downward continuous casting machine

Chapter III: Manufacturing of vertical downward continuous casting machine.

Introduction:

This chapter is devoted to the manufacturing of the vertical downward continuous casting machine and its functions. Furthermore, some examples of products produced by this machine and their characterization are also presented.

1. Vertical downward continuous casting machine:

A basic overview of the continuous casting machine following the final assembly of all of its components is presented in figure III.1.

Figure III.1: The continuous casting machine's final shape.

2. The parts of continuous casting process:

This machine is made up of three parts, as shown in figure III.1:

- ✓ Heating system.
- ✓ Cooling system.
- ✓ Mechanical system (pulling).

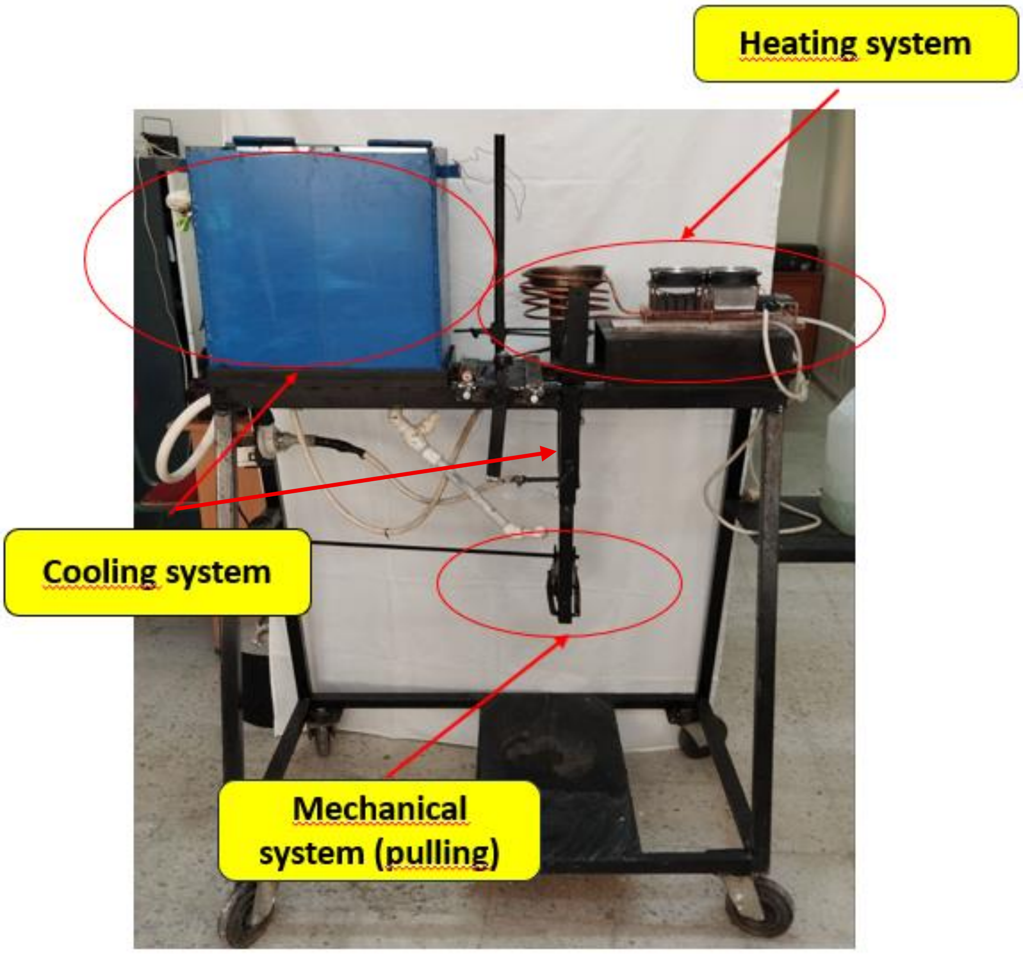


Figure III.2: Different parts of the continuous casting machine.

2.1. Heating system:

This system contains an induction furnace, which is divided into two parts, the induction heating device and the graphite crucible.

2.1.1. The induction heating device:

Induction heating is the process of heating electrically conductive materials, namely metals or semi-conductors, by electromagnetic induction, through heat transfer passing through an inductor that creates an electromagnetic field within the coil to heat up and possibly melt steel, copper, brass, graphite, gold, silver, aluminum, or carbide.

An induction heater consists of an electromagnet and an electronic oscillator that passes a high-frequency alternating current (AC) through the electromagnet. The rapidly alternating magnetic field penetrates the object, generating electric currents inside the conductor called eddy currents.

The figure III.3 shows the induction heating device used in heating system.

Figure III.3: The induction heating device with its power supply.

Using the induction heating device, we were able to reach a temperature of 1089°C inside the crucible, which was measured using a thermocouple, as shown in the figure III.4.

Figure III.4: Measure the temperature inside the crucible using a thermocouple.

2.1.2. The graphite crucible:

As information, graphite crucibles are high-temperature vessels used in metallurgy and materials science for melting metals and heating substances under controlled conditions. They are durable and resistant to chemical corrosion, and come in various sizes and shapes for specific applications. The graphite crucible used here is a 1 kg crucible with a height of 125 mm and an inner diameter of 38 mm.

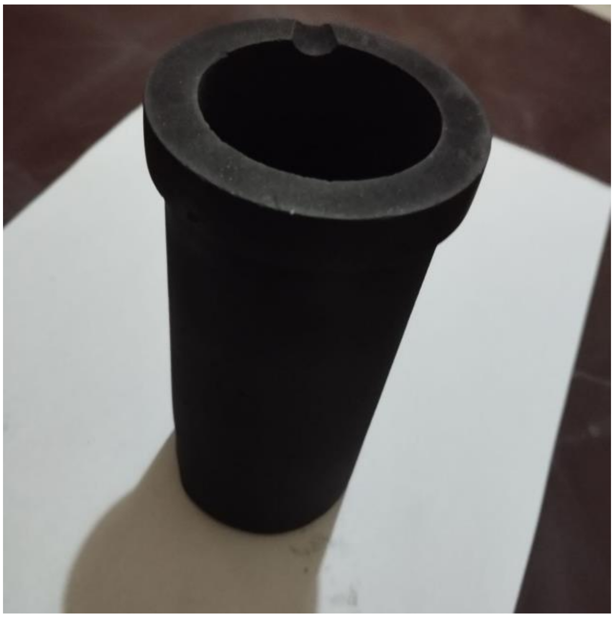


Figure III.5: Graphite crucible.

2.2. Cooling system:

There are two different types of cooling: The first types occurs at the crystallizer's level, where an internal water circulation tube is part of an open hollow structure. and the second type is secondary cooling, which enables direct cooling and control over solidification of the cast product over the whole casting line located at the crystallizer's bottom. Water spray guarantees the cooling of the rollers in this region and the stiffness of the casting wire to support the efforts of the guide rollers.

2.3. Mechanical system (pulling):

Within the secondary cooling area, the pulling area is an essential component. Two rollers make up this set. Two are used: one is adjustable to guarantee that the metal is transported from top to bottom, and the other is fixed to establish the direction of casting. These wheels are intended to provide guidance.

3. Vertical continuous casting's manner of operation:

The vertical continuous casting machine operates in the following manner :

1st step: we insert the metal wire with a diameter 6 mm into the crystallizer unit until it reaches the top level of the hole on the graphite crucible.

2nd step: we run the main cooling system.

3rd step: we turn on the induction heating device and check it.

4th step: we put the metal for casting process (aluminum or copper) inside the graphite crucible and wait until it melts completely.

5th step: we start with the pulling process 3 cm/s.

4. Experimental results:

Several tests were conducted using the vertical downward continuous casting machine and some samples were manufactured.

Test 1: for the first experiment, we used about 200 g of copper and placed it in the graphite crucible. After we made sure it was completely melted, we extracted it and got the following sample (Figure III.6).

Figure III.6: A copper sample obtained by the continuous casting machine.

Test 2: in the second test we melted about 200 g of aluminum alloy, then we pulled at a rate of 10 mm/min and stopped for five seconds, then continued the process and repeated.

At the end we got the following sample (Figure III.7).

Figure III.7: Aluminum alloy sample manufactered by the continuous casting machine.

We divided the aluminum alloy sample into two halves and then polished it by abrasive paper (120 / 180 / 240 / 600 / 800 / 1200 / 2500) and polishing cloth with diamond past.

Figure III.8: Abrasive paper.

After completing the polishing, we placed the sample (figure III.9) under the optical microscope to obtain a clear view (figure III.10).

Figure III.9: Aluminum alloy sample after the polishing.

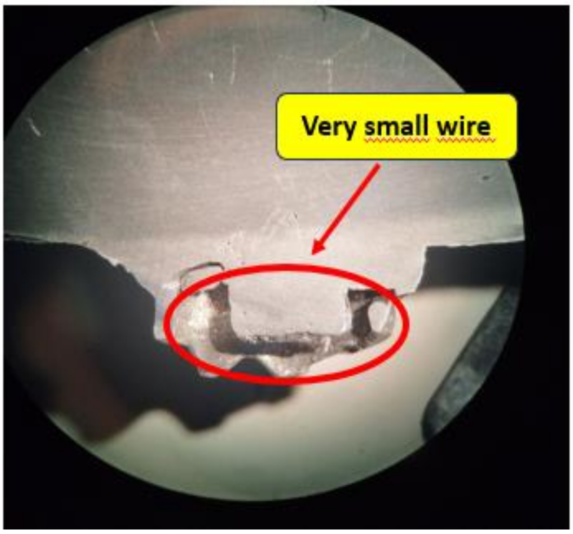


Figure III.10: The aluminum alloly sample under the optical microscope.

As we can see in (figureIII.10), we pulled out a very small wire estimated at 5 mm.

Test 3: In this experiment, a mechanical vibration was used to help the melted metal go down and we replaced the graphite crucible with a stainless steel funnel (figureIII.11). In this test, the source of the vibration used is a micro vibration motor (figureIII.12) which works with electrical voltage of 3.7 V and it gives a frequency of 100 Hz.

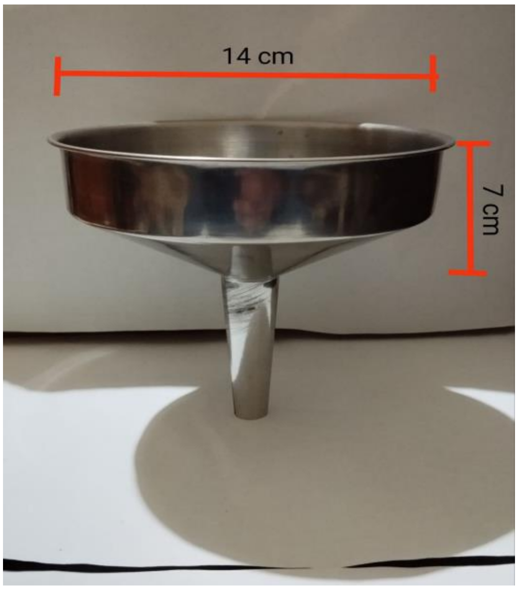


Figure III.11: Stainless steel funnel.

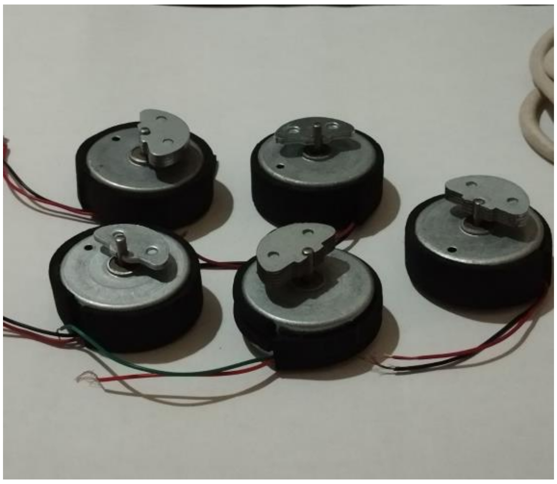


Figure III.12: Micro vibration motors.

To achieve this mechanical vibration, We attached the micro vibration motor with the funnel, then we melted the aluminum in an electric furnace, after that we poured it into the funnel with the presence of vibration and we get the following sample.

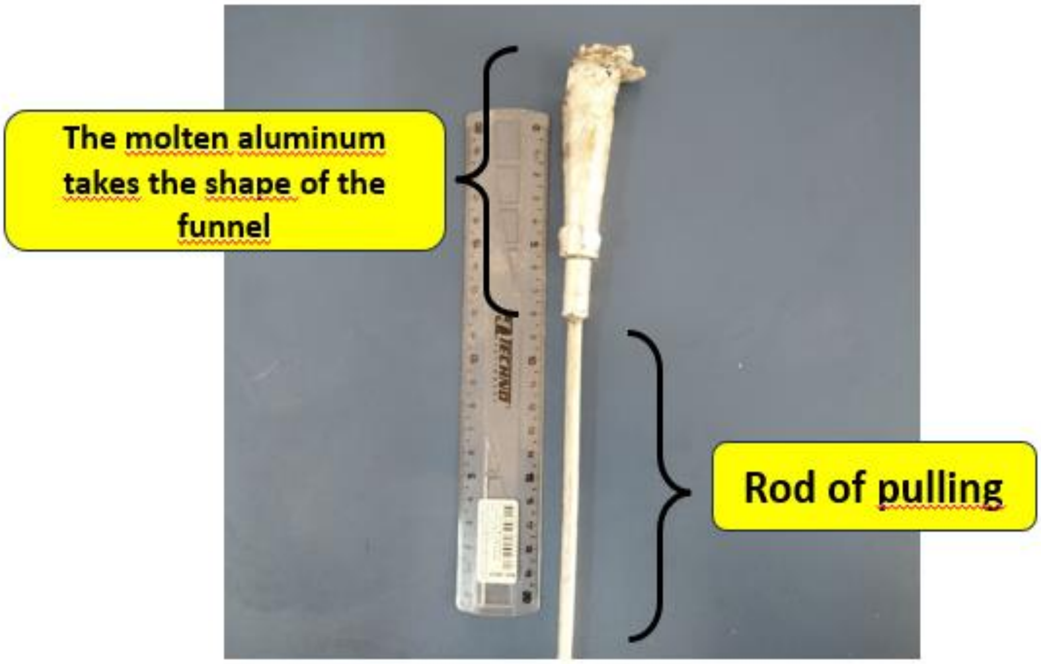


Figure III.13: Aluminum alloy sample manufacted by continuous casting machine under mechanical vibration.

Test 4: in this experiment, we repeated the same steps as the previous test, only changing the vibration link method from funnel to the mold (crystallizer) and also we change the rate of pulling, we pull at rate of 3 cm/s in presence of the vibration. As presented in figure III.14, we succeeded in extracting about 13 cm of aluminum, and this result is satisfactory.

Figure III.14: Aluminum alloy cast sample manufacted by continuous casting machine under mechanical vibration.

5. Characterization of cast aluminum alloy:

5.1. Microstructural observation:

For microstructural observation cross section of cast sample (Test 4) was cut into two samples and polished with abrasive paper (120 / 180 / 240 / 600 / 800 / 1200 / 2500) and finished by the polishing cloth with diamond past.

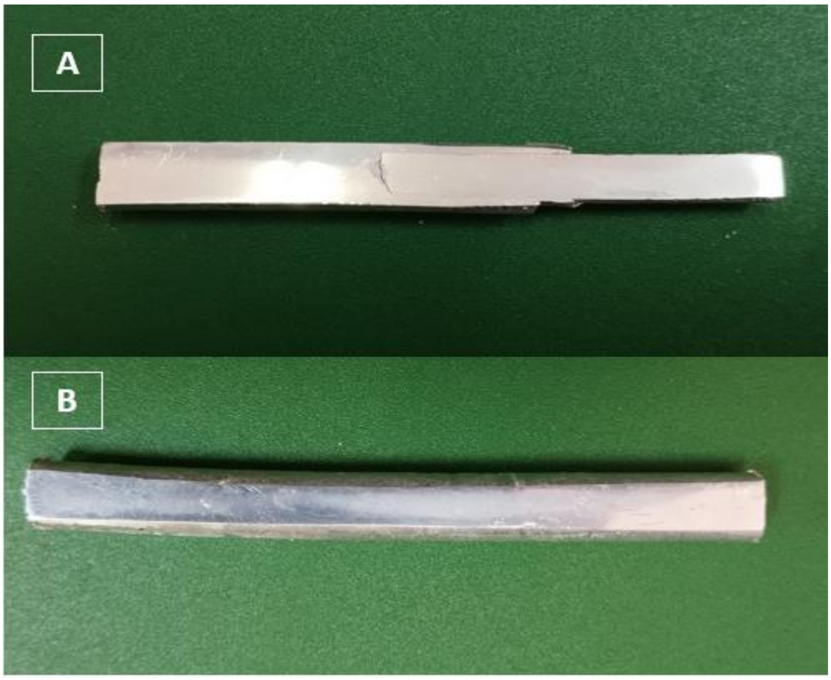


Figure III.15: A macrographic view of the two samples (A, B).

Figure III.16: Abrasive paper and polishing cloth.

The polished samples were etched by Keller solution (190 ml of distilled water + 5 ml nitric acid + 10 ml hydrochloric acid + 2 ml hydrofluoric acid) during 3s. The etched samples were observed by optical microscope (Olympus) as shown in figure III.17. As it is presented in this figure, fine oriented grains (grain size = 10 µm) with some segregation at grain boundaries (dark color) were obtained which it is due to the solidification process during the continuous casting process. It has been observed that the metal obtained by continuous casting does not contain any internal defects such as pores which shows the efficiency of this machine.

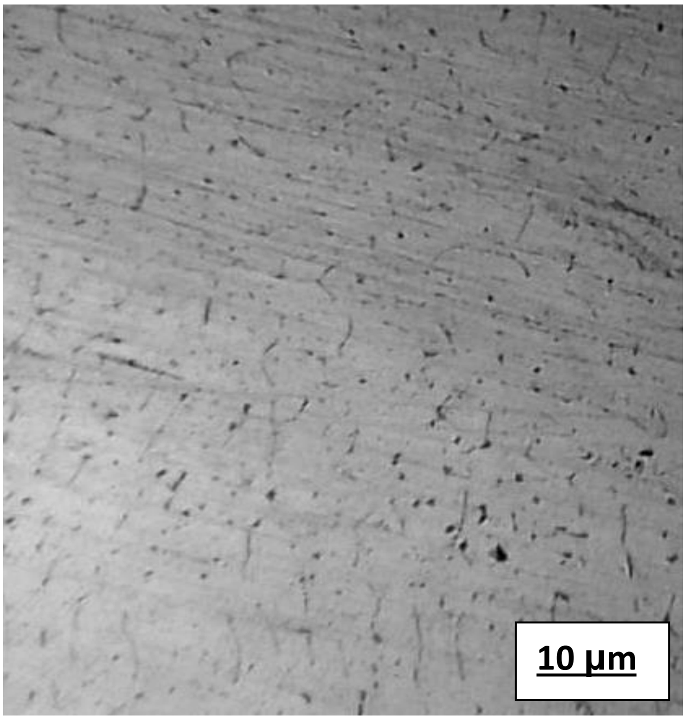


Figure III.17: Microstructures of cast aluminum alloy sample.

5.2. Hardness measurement:

The hardness measurement was also measured and performed by using Vickers hardness apparatus. Hardness measurement was performed along the longitude axis of cast sample under 200 g as charge during 10 s. The Vickers hardness value is 62.9 HV . which is a value that is within the range of values of certain aluminum alloys.

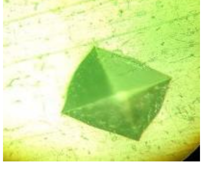


Figure III.18: Micro graphic view of the imprint of Vickers at the cast sample.

5.3. The Temperature-time (T-t) curve:

Figure III.19 the temperature-time curve (TT)(Fig.III.19a) recorded during a solidification test (Fig.III.19b) of the aluminum alloy used in continuous casting tests. It can be observed that the cooling is rapid at the start of this test which shows the rapid speed (less than 2 minutes) of solidification of aluminum. Then, the cooling rate decreases gradually and very slowly until the solidified metal has completely cooled. This last stage lasts approximately 48 minutes.

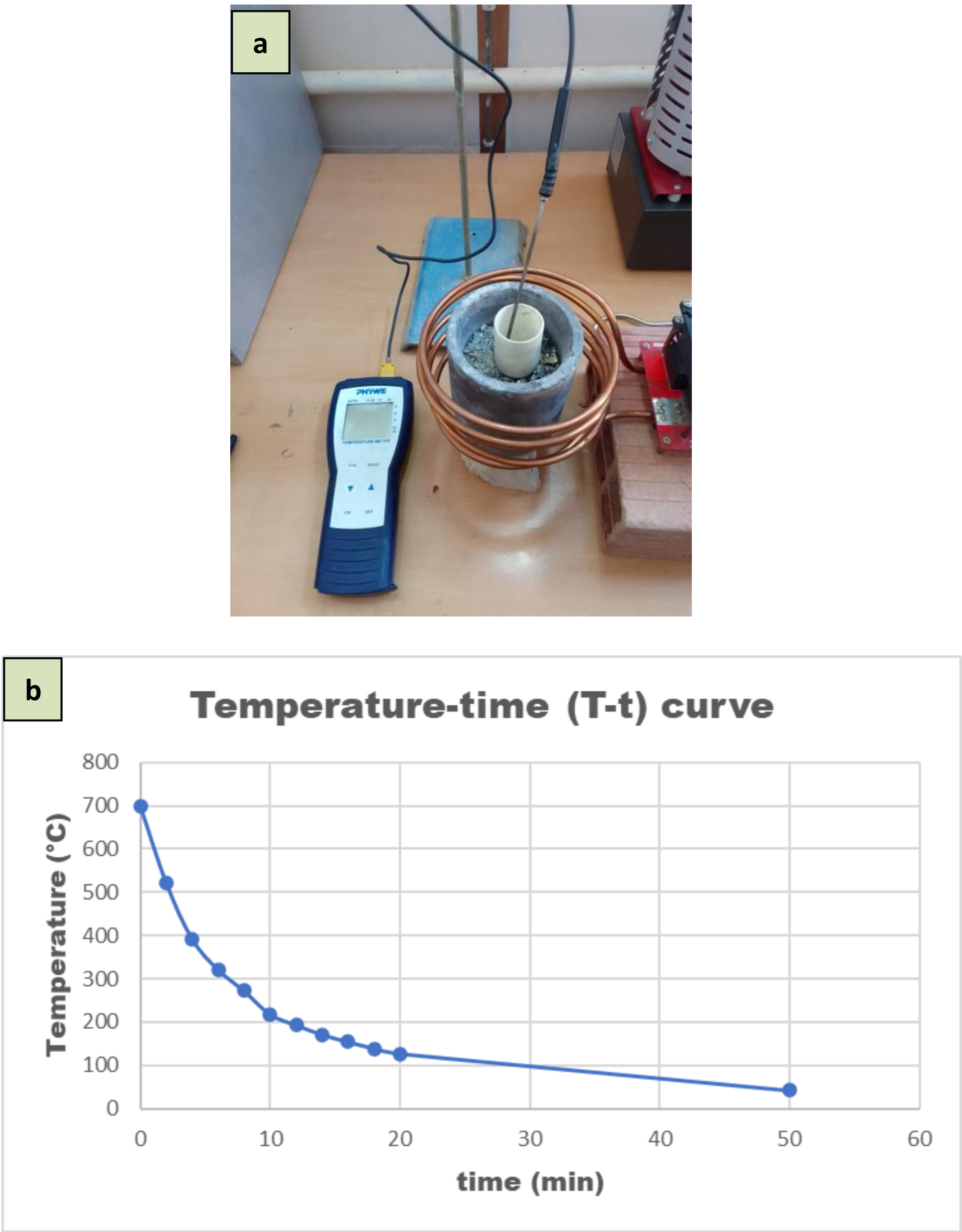


Figure III.19: (a) Solidification test of aluminum alloy. (b) : The Temperature-time curve.

General Conclusion

The objective of this thesis was to manufacture a small vertical downward continuous casting machine based on the last machine manufactured the previous year. After several attempts, a small continuous casting machine was successfully produced

The following components make up the majority of the manufactured machine:

- Heating system.
- Cooling system.
- Extraction system.

The heating system is based on the use of a furnace which operates on induction which allows metals to be melted at high melting temperatures such as copper. This heating method is considered an improvement on the previous machine.

This machine has another characteristic which is its simple handling. In addition, was powered by a mechanical vibration system to facilitate the pouring of the molten metal downwards.

Several continuous casting tests were carried out which made it possible to produce an aluminum wire 13 cm long. This same wire was characterized by optical microscopy and microhardness measurement to deduce its mechanical properties. The metal obtained by continuous casting does not contain any internal defects such as pores which shows the efficiency of this machine.

Outlook:

It will be preferable to make several heads and automate the pulling system so that it works automatically.

Abstract

The objective of this dissertation is to produce a machine for the downward vertical continuous casting of metal wires.The machine is mainly composed of the following parts: heating system, cooling system and pulling system. The heating system is based on induction heating. The continuous casting tests on this machine were carried out successfully, which made it possible to manufacture an aluminum wire 13 cm long.

Résumé

L'objectif de cette thèse est de réaliser une machine pour la coulée continue verticale vers le bas de fils métalliques. La machine est principalement composée des parties suivantes : système de chauffage, système de refroidissement et système de traction. Le système de chauffage est basé sur le chauffage par induction. Les essais de coulée continue sur cette machine ont été réalisés avec succès, ce qui a permis de fabriquer un fil d'aluminium de 13 cm de long.

ملخص

الهدف من هذه الأطروحة هو إنتاج آلة للصب المستمر الرأسي للأسلاك المعدنية. تتكون الآلة بشكل رئيسي من الأجزاء التالية: نظام التسخين، نظام التبريد ونظام السحب. يعتمد نظام التدفئة على التسخين التعريفي. تم إجراء اختبارات الصب المستمر على هذه الآلة بنجاح مما مكن من تصنيع سلك ألومنيوم بطول 13 سم.