ZANCO Journal of Pure and Applied Sciences
The official scientific journal of Salahaddin University-Erbil
https://zancojournals.su.edu.krd/index.php/JPAS

ISSN (print):2218-0230, **ISSN (online):** 2412-3986, **DOI:**

RESEARCH PAPER

Semi Solid Casting of Aluminum Alloy Using a Cooling Slope Technic.

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A B S T R A C T:

In this study, semi-solid metal casting technology has been used to make castings from Al alloy 6063 scrap using different casting temperatures and a cooling slope of 30cm long. The purpose of the cooling slope was to cool down the liquid metal into a semi-solid state of about 60% liquid before entering the mold. The results showed that the semi-solid metal cast samples that pass over a cooling slope had higher strength and ductility as compared to the traditional direct casted samples due to the evolution of microstructure from dendritic into globular morphology. A ductility increase over 38%, 100%, and 34% is recorded for semi-solid casting over a cooling slope compared to direct casting for liquid metal at 750^{o}C, 800^{o}C, and 900^{o}C respectively. Strength is improved by about 8% for semi-solid casting at 750 and 900^{o}C compared to direct casting. For 800^{o}C no improvement is recorded in terms of the tensile strength for cooling slope over direct casting

KEY WORDS: Al alloy 6063, Semi-solid casting, Cooling slope, Mechanical properties, Structure morphology.
DOI: http://dx.doi.org/10.21271/ZJPAS.32.3.6
ZJPAS (2020) , 32(3);49-56 .

1. Introduction

Through the last fifty years, a lot of casting techniques have been used which allowed engineers to make the most complex shapes and parts from any metals or their alloys. Semi-solid metal (SSM) is a new metal casting technology that is different from the traditional metal casting technologies that use liquid metals as starting materials. Semi-solid metal (SSM) processing is the process of creating near net complex shape from feedstock's that are a non-dendritic in microstructure in a liquid state.

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Article History:
Received: 11/12/2019
Accepted: 23/01/2020
Published: 15/06 /2020

Prof. Fleming and his Ph.D. student Spencer was the first who discovered the first idea of a semi-solid process in the 1970s during work on the hot tearing of lead-tin (Sn - 15% Pb) alloy. They discovered that the materials that continuously stirred had spherical microstructure compared to non-stirred material which has a dendritic microstructure (Spencer 1971). There are two main technologies for the casting of semi-solid metal (SSM) parts; rheocasting and thixocasting. Rheocasting includes melting the metal of dendritic structure and cooling it to its semi-solid state to change the microstructures from dendritic to a spherical and non-dendritic shape by using a suitable technic then injecting the resulting slurry into a die (Pola, Tocci et al. 2018) (Kirkwood 1994). In the thixocasting process, a solid feedstock of non-dendritic microstructure is used and reheating to its semisolid temperature then formed into a die. The most implemented routes that have been used for producing non-dendritic grains are: Mechanical Stirring, Magneto Hydrodynamic (MHD) stirring, Cooling slope process, Stress-Induced and Melt-Activated (SIMA) Process, Direct Partial Re-melting (DPRM), Swirled Enthalpy Equilibration Device Process (SEED), Ultrasonic Vibration method, Shearing-Cooling Roll method, Gas-Induced method (GISS) and Continuous Rheoconversion method (CRP) (Mohammed, Omar et al. 2013) (Hirt and Kopp 2008) (Kirkwood, Suéry et al. 2010). Semi-solid metal forming has many advantages over traditional direct casting such as increasing the die life because of decreasing the thermal shock, lower porosity and macrosegregation and it has lower processing cost with better mechanical properties such as higher ductility and higher strength (Nafisi and Ghomashchi 2005). Among all the techniques used to produce semisolid feedstock, the cooling slope is the easiest process and the most cost-effective. This is why it attracted research works worldwide. (Gencalp and Saklakoglu 2010) have presented that when vibrate the cooling slope channel during semisolid casting of A380 alloy, the nucleation of the particles increased and as a result, a large number of dendritic arms have been broken into spherical grains when comparing with without vibrating the cooling slope. (HAGA, R et al. 2010) have improved the cooling slope by using a cooling roll having a V-shaped groove that continuously rotated at 5 and 10 meter/minute providing a cool and new flow path for the molten liquid and they found that this method has prevented the adhesion of the liquid metal to the cooling slope especially when the cooling path was rotating at 10m/minute in which the adhesion of the solidifying metal to the cooling path is totally eliminated. (Prosenjit, Ray et al. 2012) studied the effect of the tilt angle of the cooling slope and grain refiners on grain morphology and tensile properties of the semi-solid Al A356 alloy. They presented that the grains had more spherical shapes when the cooling slope has been tilted at 60^o while it had some degenerated dendrites at 40^o. They also found that tensile properties were generally improved by using cooling slope compared to direct casting but the best improved occurred when small amounts of Al-5Ti-1B as grain refiner were added to the molten metal passing over a cooling slope tilted at 60^o. (Abdull-Rasoul and Hassan 2015) also investigated the effect of cooling slope tilt angle and grain refiner on mechanical properties of casted 6063 aluminum alloy. They presented that a cooling slope mounted at 30^o, 40^o and 50^o tilt angle of the semi-solid metal casting for both 0.46% Mg and 1.6% Mg had high strength and more spherical grains as compared to 60^o tilt angle.

The authors of this study found that there are a lot of scraps Al alloy 6063 in the Erbil market resulted from local factories that make door and window frames that are normally wasted into landfills and cause a lot of environmental problems. Recycling of this scrap will result in restoring huge amounts of valuable material and reducing environmental issues and on the other hand using new techniques of recycling such as semi-solid metal casting can result in the production of high-quality feedstock for a local and global market. So, the aim of this study is to produce high-quality feedstock from Al alloy 6063 scrap gathered from local factories using a cooling slope technique instead of direct casting.

2. Experimental equipment and procedures:

In this work scraps of Al alloy 6063 have been used as the starting material with the chemical composition shown in table (1). A single-phase electrical furnace of 3500W and graphite crucibles was used to melt down the scrap and superheat it to 750^oC, 800^oC, and 900^oC. A water-cooled cooling slope made from L shaped carbon steel section as shown in figure (1) has been used with an active length of 300mm and tilted at 45^o to produce the semi-solid slurry. The mold to which the semi-solid slurry flow into was made from carbon steel with a mold cavity of 35mm diameter and 240mm length as shown in figure (2). Each time 500g of the scrap was fed into the furnace and melted and superheated to the desired temperature then poured the molten metal into the cooling slope plate running down into the mold cavity and left in the air to be cooled to room temperature. Three different procedures were used for comparison, one is by direct pouring the molten metal into the mold cavity, the second was by pouring the molten metal onto the cooling slope cooled with circulating water, and the third was by pouring the molten metal onto cooling slope with no water circulation. The resulted feedstocks from the three different procedures were then sectioned according to ASTM E3 and E112 for microscopical examination to study grain structure morphology and to investigate tensile properties according to ASTM B557.

Table (1) chemical composition of 6063 aluminum alloy

Al %	Mg %	Si %	Fe %	Cu %	Cr %	Zn %	Ti %	Mn %
98.88	0.434	0.387	0.16	0.0117	0.0038	0.0265	0.004	0.0443

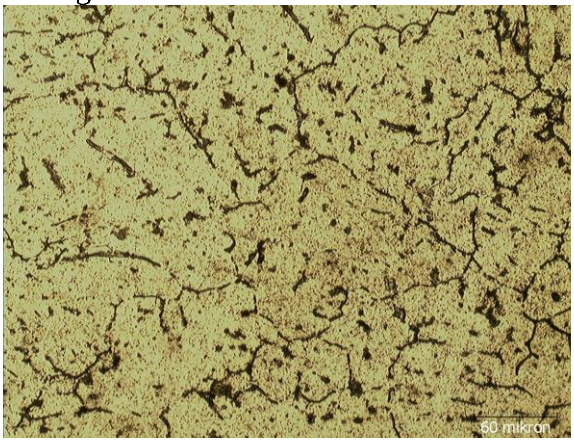
Figure (1): The cooling slope device.

Figure (2): the Mold.

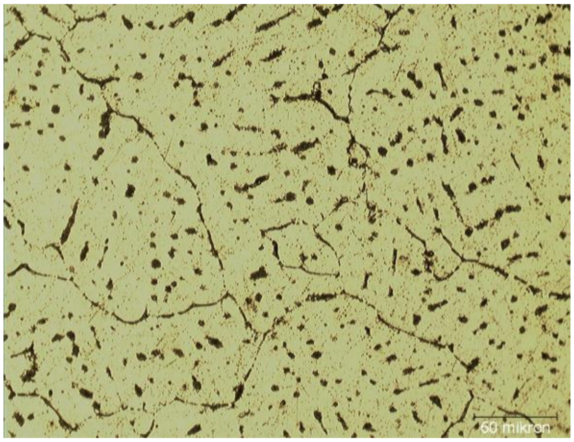
3 Results and Discussions

3.1 Grain Morphology:

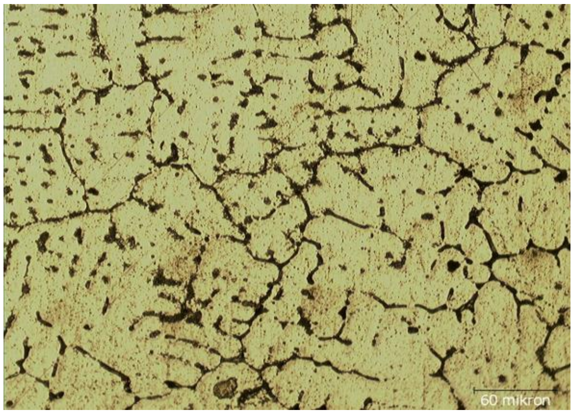
From the microstructure evaluation, we found that the samples have dendritic structures when direct cast from 750°C, 800°C and 900°C as presented in figure (3). The average grain size according to the Linear intercepts method as per ASTM E112; was found to be 60µm at 750°C. Increasing the casting temperature to 800°C the average grain size increased to 75µm and 80µm at 900°C with a clearer dendritic grain texture. While the samples that passed over the cooling slope had shown a different in grain morphology and nearly spherical shape with a smaller size. Using a cooling slope produced a very fine globular non-dendritic and more homogenous grain. When the molten alloy poured onto the cooling slope it will solidify during flowing down along the cooling plate as the result the temperature of the slurry is decreased to below its liquidus temperature usually near 550^{o}C in which only about 60% is still liquid and solid nuclei start forming. The primary particles of the solidus will be nucleated and grow over the wall of the plate and detached because of the shear stress of the incoming molten alloy flow. They flowed to the mold and before becoming dendritic in structure they will be solidified as a result the average size of the grains will be reduced dramatically. Comparing the grain texture from the figure (3) and figure (4); it can be seen that grain texture has greatly evolved and totally turned into a globular morphology for different pouring temperatures. Figure (5) shows that the average grain size lays between 29 and 40μm when using a cooling slope while it was between 60 and 80μm for direct casting from the same temperature. Using water cooling within the cooling slope does not have a great effect on the grain size and morphology.



(a) Casting at 750°C.

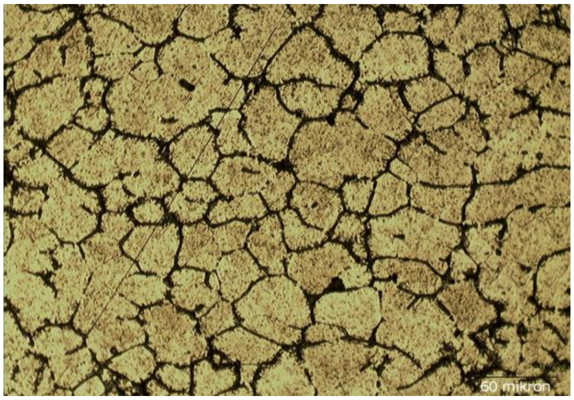


(b) Casting at 800°C.

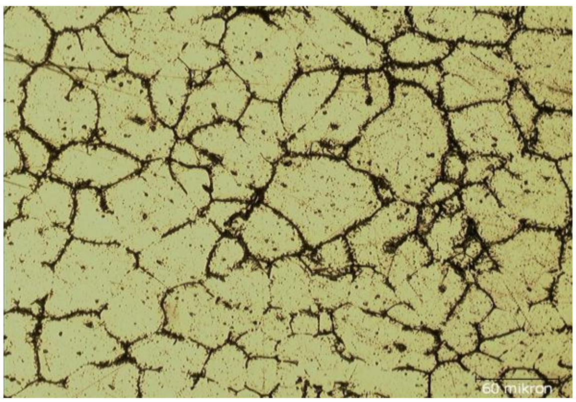


(c) Casting at 900°C.

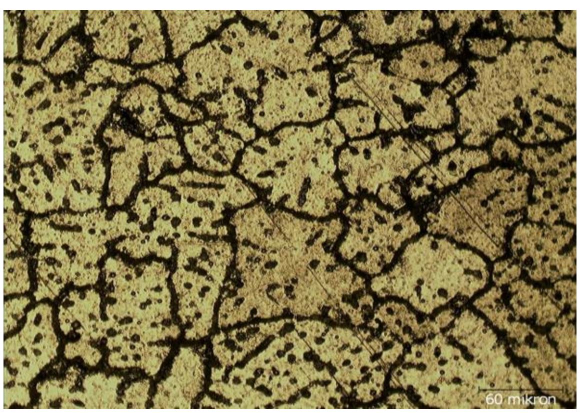
Figure (3) Grain texture and morphology of direct casted samples at different casting temperature. X150



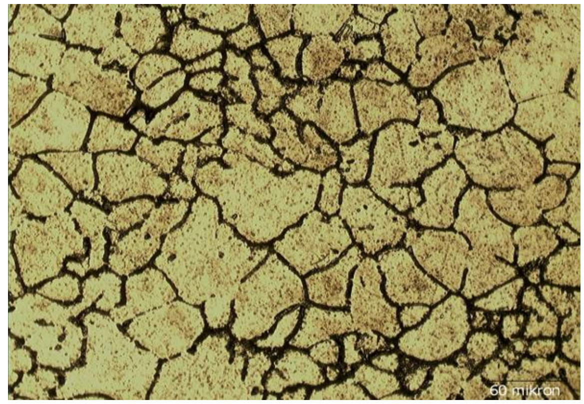
(a) Cooling slope rheocasting with water cooling at 750°C. X150.



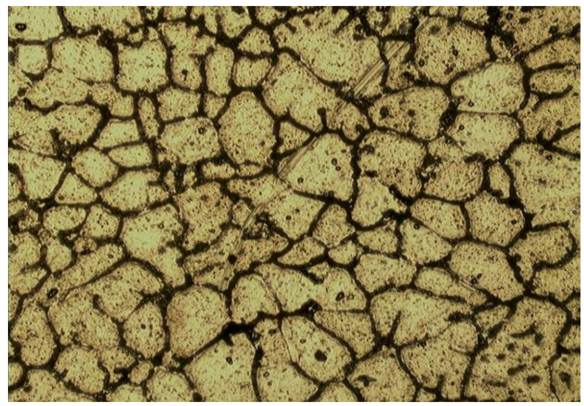
(b) Cooling slope rheocasting without water cooling at 750°C. X150.



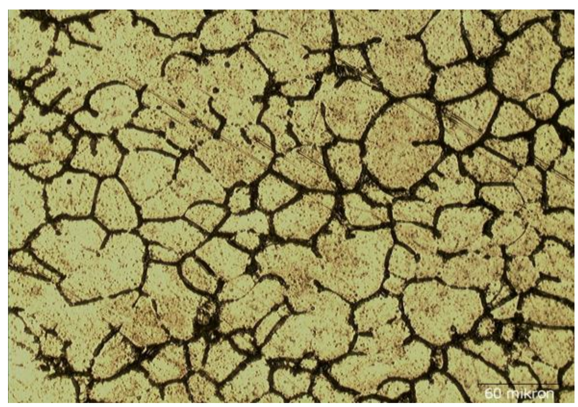
(c) Cooling slope rheocasting with water cooling at 800°C. X150.



(d) Cooling slope rheocasting without water cooling at 800°C. X150.



(e) Cooling slope rheocasting with water cooling at 900°C. X150.



(f) Cooling slope rheocasting without water cooling at 900°C. X150.

Figure (4): semi-solid casted samples microstructure at different conditions.

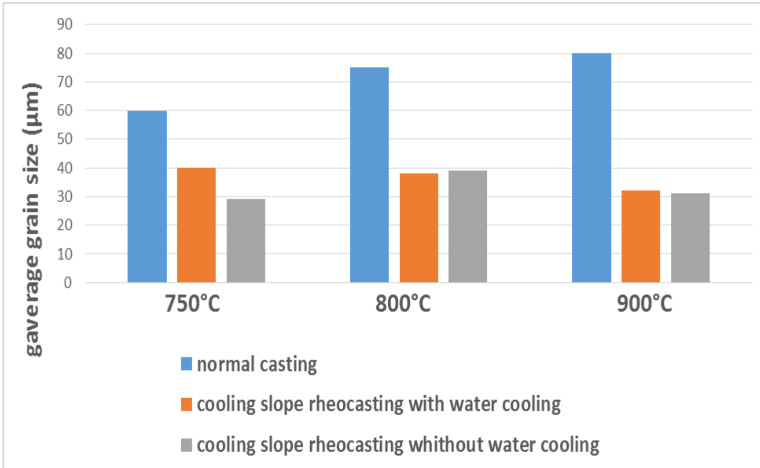


Figure (5) Relation between grain size and casting temperature at different casting conditions.

3.2 Tensile Test:

A universal computerized tensile testing machine of the capacity of 600KN was used to determine the strength and ductility of the casted samples. Tensile strength and ductility of metals and alloys are usually a reflection of its grain structure and morphology. Table (3) illustrate tensile properties of the direct casting of Al alloy 6063 at three different casting temperature of 750°C, 800°C and 900°C while table (4) shows the tensile properties of the same alloy when casting over a cooling slope from the same temperatures. The improvement in tensile properties is quite clear and is attributed to the changes have seen in the microstructure morphology. Figure (6) presents a tensile test result of three samples one obtained from direct casting from 800^{o}C and the other two samples obtained from the cooling slope casting at the same temperature with and without water circulation. There can be observed an improvement of both the ductility and the tensile strength and the highest improvement was recorded in terms of ductility of about 100% when using a cooling slope with no water circulation. It can be seen from figures (7) and (8) that there is a general improvement in mechanical properties by increasing the strength and ductility as a result of replacing the primary phase structures from dendritic to a globular and non-dendritic shape and by reducing grain size and morphology using a cooling slope semisolid casting process. Ductility increased to about 38%, 100% and 34% for semi-solid casting over a cooling slope compared to direct casting for liquid metal at 750^{o}C, 800^{o}C, and 900^{o}C respectively. Strength is improved by about 8% for semi-solid casting at 750^{o}C and 900^{o}C compared to direct casting. A very little or it can be said that there was no improvement in strength for samples cast from 800^{o}C for cooling slope over direct casting. It was also observed that using water circulation with the cooling slope has no or very little effect on grain texture, morphology and tensile properties of the casted samples.

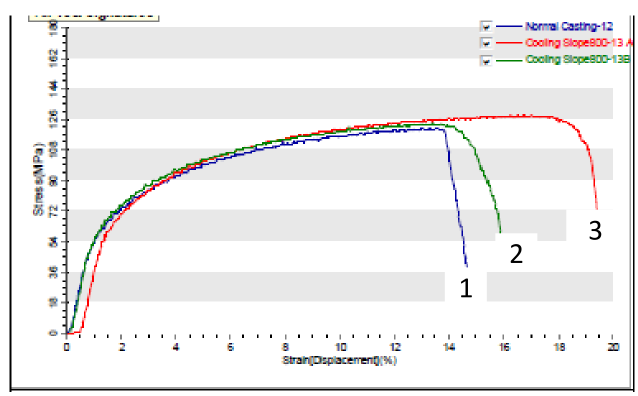


Figure (6): One stress-strain diagram of the tensile tests for three different samples;

1- Direct casting from 800^{o}C

2- Casting over cooling slope from 800^{o}C with water circulation.

3- Casting over cooling slope from 800^{o}C without water circulation.

Table (2) Tensile strength and ductility of direct cast samples.

Sample No	Casting temperature (°C)	Ultimate strength(MPa)	Ductility (%)
1	750°C	118	18%
2	800°C	126	15%
3	900°C	115	24%

Table (3) Tensile strength and ductility of semi-solid casted samples using a cooling slope.

Sample No	Casting temperature (°C)	condition	Ultimate strength(MPa)	Ductility (%)
4	750°C	Using cooling water circulation	127	22%
5	750°C	No cooling water circulation.	121	25%
6	800°C	Using cooling water circulation	127	22%
7	800°C	No cooling water circulation.	128	32%
8	900°C	Using cooling water circulation	124	32%
9	900°C	No cooling water circulation.	124	27%

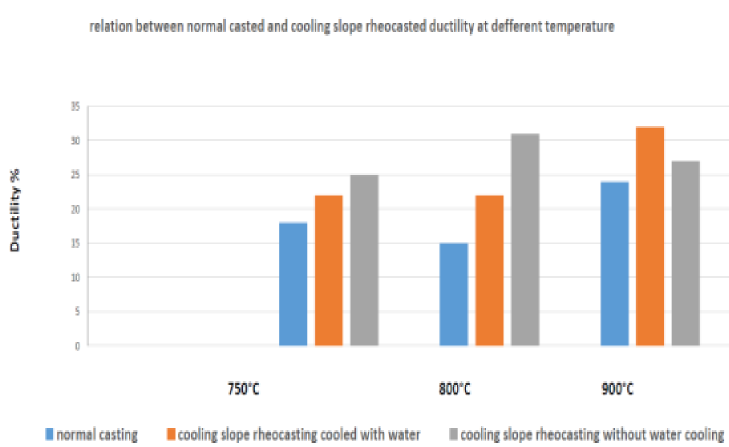


Figure (7): Relationship between casting condition and ductility at different temperatures

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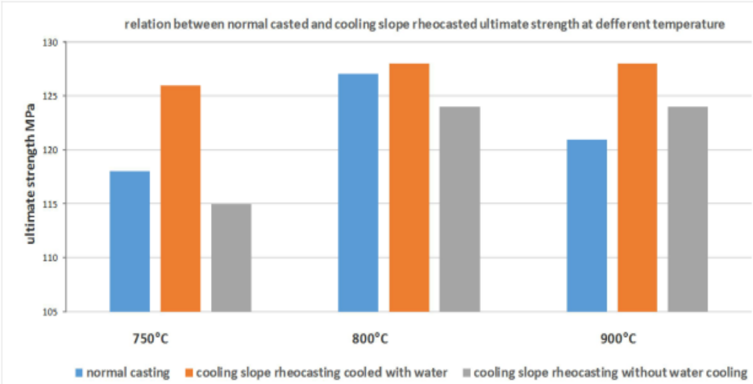

Figure (8): Relationship between casting condition and tensile strength at different temperatures.

3. Conclusions:

1- Semi-solid casting of Al alloy 6063 resulted in the evolution of the microstructure that was changed from dendritic to globular grain texture with a reduced grain size down to about 29um.

2-Ductility is greatly improved to an extent of 100% using a cooling slope when pouring temperature was 800^{o}C reduced to about 34% for higher temperatures.

3- Strength is improved to about 8% for semi-solid casting using a cooling slope and pouring temperature of 750^{o}C and 900^{o}C. Very little improvement was recorded in terms of tensile strength for pouring temperature of 800^{o}C.

4- Water circulation within the cooling slope has been found to have no or very little effect on grain morphology and tensile properties of the casted samples.

4. Acknowledgments:

These moments allow me to express my deepest thanks and gratitude to Mr. Mowafaq Izzadin; the expert and senior technicians at the mechanical engineering department who tirelessly helped us in the preparation and machining of the samples for the mechanical tests. Thank you so much, we appreciate it.

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