Unidirectional Solidification of (Al-Si) Eutectic Alloy

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Abstract

This paper provides an overview of the mechanical properties of reinforced Al-12%Si alloy by uni-directional of the eutectic phases in specific direction. A special solidification unit have been designed and manufactured to ensure the correct orientation of growing eutectic phase. Two types of insulation materials have been used to isolate the carbon steel mold of solidification unit, (dry sand and glass wool). The second type insulator found to be favorable in augmenting the growth and uni-direction of eutectic phase with the conditions of cold water flow through the unit. The produced microstructure consists of little elongated α-phase with a noticeable correct orientation of the growing discontinuous eutectic phase in the direction of heat sink. Hardness, tension, compression and impact properties have improved in comparison with the samples of free mold isolation case (i.e. free solidification). These results reflect directly the effect of uni-directional growth of eutectic phase in the reinforcement process of the investigated alloy as an in situ-composite material.

ألخلاصة

يقدم هذا البحثِ نظرة مفصلة على الخواص الميكانيكيةِ الناتجة من تقوية سبيكة ألمنيوم- 12%سيلكون بواسطة توجيه طور اليوتكتك باتّجاهِ واحد ومعيّنِ. ولتحقيق هذا الهدف فقد تم تصميم وتصنيع وحدة تجمّدِ خاصّةِ لضمان التوجيهِ الصحيحِ لنمو طور اليوتكتك . وقد تم عزل القالب ضمن هذه الوحدة بنوعين من موادِ العزلِ (رمل جاف وصوف زجاجي). وَلقد وجدَ أن العازلُ الثاني يَكُونَ مناسبَ في دَمْج النمو وتوجيه طور اليوتكتك مع شرط تدفقِ الماءِ البارِدِ خلال الوحدة مقارنةِ بظروف العزل الأخرى التي اعتمدت في هذا البحث. وقد أثبتت فحوصات البنية المجهرية حصول التوجيه الأحادي ألاتجاه مما نتج عنه تقوية السبيكة مقارنة بحالة السبيكة في الأنجماد غير ألاتجاهي. كما أثبتت الفحوصات الميكانيكية تحسنا واضحا في كل من خواص الصلادة، الشد، الانضغاط وكذلك متانة الكسر مما يعْكسُ دور النمو الإتجاهي لطور اليوتكتك في تقوية هذا النوع من السبائك بطريقة أل(in-situ composite) أي تنمية طور التقوية من داخل السبيكة بدلا من إدخاله من خارجها كما في حالة أل(ex-situ-composite)

Such examinations have revealed that load transfer from the matrix to the “fiber” is very efficient, and that typically the fiber or whisker fails rather than the interface. This observation strongly suggests that an excellent bond is obtained between the microstructure phases, which are what might be expected, subsequent chemical reactivity between the phases is also minimized in this type of composite system. [A. K. Bhargava, 2005].

The regularity of the morphology depends mainly on [R. S. Khurmi etal., 1989 & M. M. Schwartz, 1984]:

1. The thermal gradient existing at the solidification front.
2. The solidification rate, i.e. the velocity at which the solidification front moves.

When uni-axial heat flux is released, e.g. by extracting the molten alloy from a vertical furnace. A liquid-solid interface normal to the direction of the heat extraction is formed. Under strictly controlled conditions this liquid-solid interface is planar and moves at constant velocity through the entire length of the ingot. The two phases α (i.e. matrix) and β (eutectic phase) formed at the interface follow the solidification front movement leading to the lamellar morphology with the single lamellae oriented along the direction of heat extraction.

The lamellar composite and fibrous composite structures are obtained only in the case where the solidification front is planar, perpendicular to the direction of the growth (heat extract) and the numbers of the parameters are affected, such as the thermal gradient, the solidification rate, the impurities...etc.

The morphology of a single system, however, does not remain constant when the solidification parameters are changed. The influence of the gradient seems to be minimal. While in some systems the influence of the solidification velocity is considerable. In some systems the lamellae - to rods transitions have been observed by increasing the solidification rate, while in others the opposite effect can be noted. In each case however, the transition is gradual. At very low rates some systems present degenerate structures. The interlamellar distance is also a function of the solidification rate.

2. Experiment Work

High purity (Al-12%Si) alloy used in the form of ingots in cubic form (120 x 80 x 80) mm as it was received. The average chemical composition of this alloy is given in table (1) as shown below. This examination of chemical composition was performed by using (X-MET 3000 TX-Horizon 600 series, Model 2004).

In this work a special uni-directional solidification unit has been proposed, designed and manufactured to maintain a uniform solidification of molten alloy in uni- direction. This unit as it is shown schematically with dimensions in figure (1) consists mainly from the following items:

1. Movable part: consists from the following:

   a. Mould: carbon steel mold.

   b. Double Fin: a carbon steel double fin (cross shape) connects by welding to the bottom side of the mold. The function of this fin was to increasing the surface area of the bottom end of the mold where the heat transfer was permit only from this side.

   c. Isolate space: a gap around the mold used to application of multi types of insulation materials.

2. Fixed part: consist mainly from water containers which is used contain the cold water that flow from a separate water reservoir. This water used to cooling the bottom end of the mould.

3. External accessories such as the following:

   a. Water reservoir used for cold water supplying in continuous form. This reservoir installed at sufficient elevation above the level of solidification unit to ensure the continuous supplying of water.

   b. Thermocouples type (K), used to monitoring and measuring the molten alloy temperature.

   c. Two types of insulation materials, consist of:

      i. Fibrous insulation (glass wool) with a (thermal conductivity: 0.33 $W.m/m^2.^0C$).

      ii. Dry sand with a (0.33 mm) grain size and (thermal conductivity: 0.038 $W.m/m^2.^0C$) [Dr. Khalid A. Al-Judi,1986].

Thermal analysis of the alloy under investigation was done firstly at the three conditions remembered in table (2). The drop in temperature during solidifications have been measured and documented for subsequent analysis as shown in the next article. The eutectic temperature in this work assumed to still constant since there is no additions of modifiers like Sr or Na. The technique that used during the solidification and improvement of the grown eutectic phase has been proposed, designed and manufactured according to many assumptions:

1. The molten alloy should be kept in its pouring temperature as much as possible at the mold.
2. Preventing any heat dissipations through the walls and keeping only one direction as a heat sink.
3. The heat sink direction promoted the direction and growing the eutectic phase.

The production technique consists of used the different isolates material around of the mould from each side except the bottom end where a heat escape was permitted. The mould with the attached fins and insulate gaps are designed to separate from the water container solidification unit as shown in figure (1). The mould and its accessories are now heated to $700^{\circ}C$ in electric resistance furnace firstly. The reason behind the heating of mold was to keep the material in molten state as much as possible. The general plan for melting and production of ingots according to the conditions remembered in table (2) can be summarized as follows:

1. Pre-heating of solidification unit movable part in an electric resistance furnace to$700^{\circ}C$ for sufficient time (sufficiently to melt a suitable weight of Al-Si alloy in other an electric resistance furnace by using a graphite crucible).

2. After melting completion of eutectic alloy and super heating to $700^{\circ}C$, the movable part is reassembled to the fixed part. Keep in mind the movable part originally equipped with the required insulation material.

3. Cold water now must flow to the fixed part of solidification unit and pouring of molten alloy is commenced.

4. The pouring of molten alloy must be uniform (i.e. without disturbances) to avoid the hydrogen pick up and gas porosities.

5. Keeping water flow continued even the solidification of alloy has completed by (30 minutes) to ensure a complete escape of heat via the lower part of solidification unit.

6. The above procedure was repeated for each conditions remembered in table (2).

A set of mechanical testing were used to evaluate the improvement in mechanical properties of the produced ingot samples. These testing include the following:

1. Tension test: tensile test samples with a dimensions of (Lt=100, Lc=30, Lo=14, b=6, r=12) as shown in figure (3). .
2. Compression test: compression test with a parallelepiped cubic shape sample with a dimension of (9mm x 10mm).
3. Impact toughness test: impact test, where Charpy type choosed.

In addition to the mechanical testing above, a systematic microstructural observations were accompanied the producing of each samples type according to the conditions in table (2). Samples for each type of testing above were produced under high attention during choosing, machining in required dimensions according to the ASTM standard:

Microstructure evolution in all types of samples produced was done after very carful sampling and preparation under light microscopy. All samples for microstructural observations were grinded with (100, 200….1500) grit size emery paper, polished in two stages; rough and fine by using alumina solution. Finally samples were etched by using:

5%HF + 95%H_2O (distilled), [R.E. Smallman, 1999]

Optical microscopy type (Union/ME-3154) equipped with a digital camera used to reveal the choosing samples of microstructure.

3. Results & Discussion

The following results presented and discussed the unidirectional solidification of Al-12%Si alloy by studying the effect of insulation material on the nucleation, growth of eutectic phase. Mechanical properties such as (hardness, tensile, compression and impact toughness properties) of the produced alloy under adopted conditions of solidification have been studied. The microstructure evolution of eutectic phase was found very crucial in the process of reinforcing the alloy under investigation as an (in-situ-composite material). So, an overall evaluation could be done about the using of the eutectic phase as a reinforcement phase within the aluminum matrix.

Knowing that, the microstructure of cast Al-Si alloy ingots generally consist of columnar and an equiaxed zone. The occurrence and position of the transition between both zones was found to be influenced by casting parameters, including the temperature gradient and cooling rate [Sven Eckert..etal, 2004]. The insulation materials have been chosen according to its low thermal conductivity and also according to its large availability in the local markets.

3.1 Thermal Analysis

Temperature gradient was done as a function of solidification time across the solidified materials in the three conditions that shown in table (2). The reading of thermocouple that installed at the middle point of the mold was documented in every

30 seconds. Figure (2) shows accumulative diagram of the cooling curves that obtained for three cases or conditions shown in table (2). These curves represent a first survey on how the alloy solidifying according to the following proposed data:

1. Thermal properties of insulation material as adopted (see experimental work).
2. Steel mold with thermal conductivity of (52 W.m/ m^2 .^{0}C).
3. Pouring temperature was sustained constant at (700∓^{0}C).

As the solidification commences, the molten alloy is in thermodynamic instability according to [Yuhong Zhao..etal, 2006]. The eutectic phase can nucleate and grow due to the crystallization driving force, the solidified interface between the growing eutectic phase and the solidified matrix (i.e. aluminum) would become unstable under the following conditions:

1. Solute fluctuations (i.e. Si).
2. Heat disturbances.

The solute fluctuations is no longer works, especially at the progress of solidification (i.e. wt% of Si is constant), while the heat disturbances still the main parameter that affecting the process of second phase (i.e. eutectic phase) nucleation and growth.

3.2 Microstructure Discussion

Figure (3), shows a schematic representation of the microstructure evolution as a result of three conditions that adopted in table (2). The selection of samples location was according to the dimensions shown on the representing ingot in the same figure:

1. Microstructure obtained from the solidification process at free mold isolation conditions. Samples for microstructural observations were selected at the middle point of ingot height as labeled by (a) in figure (3).
2. Microstructure obtained from the solidification process of molten alloy when the mold isolated by dry sand with the cooling water flow at the bottom part of solidification unit. Samples for microstructural observations were choosed at three points as indicated by (b, c and d) in figure (3).
3. Microstructure obtained from the solidification process of molten alloy when the mold isolated by glass wool with the cooling water flow at the bottom part of solidification unit. Samples for microstructural observations were choosed at three points as indicated by (e, f and g) in figure (3).

Now, referring to figure (3), it can be seen the following features in micrograph labeled (a):

1- Homogeneous distribution of aluminum grain size throughout the microstructure of solidified material due to the homogeneous cooling rate of the mold by an air through the outer surfaces (i.e. still air).
2- Coarse grain size could be observed at the core of solidified material ingots due to the low cooling rate.
3- Little growing eutectic phase that irregular distributed and oriented along the solidified material due to many direction of heat sink (i.e. many cooling directions).

An irregular orientation and distribution of eutectic phase can be seen in figure (3-a) coming as a result of irregular very little growth of eutectic phase due to the undirected solidification or cooling. The eutectic phase appears in the microstructure above could be seen in most commercial Al-Si eutectic alloy casting that solidified in this manner (i.e. free mold isolation condition) or free solidification with no modifiers addition to the molten material such as sodium or strontium.

Micrographs in figure (3) which labeled as (b, c and d) indicate the following; a better growth of eutectic phase and its orientation in specific direction. In this conditions (i.e. using dry sand in mold isolation…etc.), the liquid alloy, poured into the unit above (i.e. unidirectional solidification unit) (see figure (1)), the temperature now falling down starting from the bottom end of mold, this falling in temperature coming as a result of cooling by cold water flow at the end bottom of mold. The efficiency of end cooling is augmented by welding a large scale double fin (i.e. in order to increase the surface area of the mold end). The heat transfer now is increases in this direction while it is seized in other directions of mold by insulated with dry sand as it was stated above. The amount of heat transfer is dependent on various factors:-

1- Geometry of the mold and the type of mold material used (which is constant a long the experiments types).
2- The insulation conditions (i.e. thermal properties and physical properties of the material used as an insulator).
3- The presence of cooling devices [M.Rappaz, 1993].

Thermal conductivity of the dry sand is very low (i.e. 0.33 $W.m/m^2\ ^oC$) so that it plays an important role by impeding most of heat that transferred across the molds surfaces (except the bottom side).

Micro-structural observations have been conducted at each specific section where the sample was chase as shown in figure (3). The samples are machined under careful conditions and parallel to the y-axis (i.e. solidification direction). The microstructures are taken parallel to the Y-axis at specific locations. These samples at those locations represent three different cooling rates regimes according to its location distance from the cooled bottom end. The microstructure micrograph at point or section (b) is different from (c and d) microstructure. Cooling rate is very low at this point in comparison with the points (c and d) due to its location away from the cooled bottom end.

Now according to this cooling rate, gas porosities and micro porosities nucleates and grows with the formation of primary Si due to the high alloy content of silicon. At sample (c), where a moderate cooling rate could be achieved, it can be seen a truly and obvious discontinuous flaky eutectic structure forms without any micro porosity or primary Si formation. The microstructure shows a clear growing of flaky eutectic phase but miss-oriented to the right wonted direction. Sample (d) microstructure is different to some extent from the above two samples microstructures. This microstructure is attributed by the following:-

1. Microstructure of the ingot or sample generally consists from α-phase aluminum and a second phase consists from a flake- discontinuous shape eutectic phase.
2. A little elongated grain structure could be seen clearly at this section or point. The reason behind such elongated structure is the pulling process of solidification by the active cooling at the bottom end of solidification unit.
3. The orientation of eutectic phase becomes more aligned with the y-axis as the material approach to bottom end of mold.
4. The orientation now step by step becomes less oriented in the y-axis due to the decreases of cooling rate with the height of ingot and also due to the efficiency of insulation material.

It is clear from above that, the growth of eutectic phase requires a sufficient time. Preferential segregation of Al & Si occurs at high cooling rates due to shorter time available for diffusion.

The third conditions that adopted in this work in order to produce a directed grown eutectic phase are the using of glass wool insulation material around the mold (i.e. high density glass wool). The mold now isolated from above and four sides, except the bottom end which is free to cool by the cold water flow and the large surface fins area that welded at this point. The very low thermal conductivity of the high density glass wool (0.038 W.m/m^2. ^{0}C) help to prevent almost all the heat energy that transfer across the mold walls to the atmosphere and then it can help to maintain the molten material at the pouring temperature at sufficient time more than the two above cases (i.e. free mold isolation and dry sand mold isolation cases).

The long time maintaining of molten material at the pouring temperature at this condition and the continuity of cold water flow through the lower part of the uni-directional solidification unit allows the heat energy to escape in only one direction and then it works to drawing the growth process of the eutectic phase in the specified direction (i.e. required direction). The heat sink now is directed to the end bottom as it was stated above, and now the material starting to solidify from the bottom to top along the y-direction.

Diffusion activities which are the reason behind the nucleation and growth of second phase (i.e. eutectic phase) are improved. The microstructure observation shows an extinct improvement in the processes of eutectic phase growing, along the y-axis. Three sections or samples also taken to monitor the microstructure variations along the solidified material. The microstructure consists mainly from α-grains of aluminum and flaky shapes eutectic silicon as can be seen in figure (3).

The good point that observed during microstructure evolution in these conditions is the increasing of eutectic phase length which is directed in good percentage in the direction of heat sink. In addition, an elongation of grain at the first section or sample along the y-axis could be seen. That will reflect directly on the mechanical properties.

3.3 Hardness results Discussion

Brinell hardness testing survey of all the outside area of solidified Al-Si eutectic alloy supporting the results that obtained from the microstructure observations above as shown in the figure (4).

According to this figure, the reason behind such equal results of hardness in the case of free mold isolation conditions is the homogeneous grain size distribution along the material under this condition of solidification due to the almost homogeneous cooling from each side of mold. The little grown eutectic phase and its heterogeneous orientation did not make a noticeable improvement the hardness results. That will give an idea about the effect of eutectic phase orientation and its growth on the subsequent conditions of solidification.

The Brinell hardness testing survey on all the outside area of solidified Al-Si eutectic alloy in the sand mold isolation conditions can make a supporting of the results that obtained from the microstructure observations above. The hardness results are now different from that obtained in condition number one where the mold is free of isolation.

The reasons behind such variation in results of hardness is the non homogeneous grain size distribution along the material under this conditions of solidification and The clear grown eutectic phase and its better orientation in the required direction of solidification. That will augment the idea about the role of eutectic phase orientation and growth on the improvement of mechanical properties of the material that reinforced with this phase.

The change of the microstructure near the end bottom of the mold was due to the low cooling rate at this section (i.e. section A) where the heat transfer is seized in efficient manner except from the bottom end of mold.

According to the figure (2), a long time resulted until the complete solidification of ingots at this condition (i.e. glass wool insulation mold). It is clear that, the diffusion kinetics now found sufficient time to work properly in this condition, but the better mold insulation (i.e. keeping or maintaining pouring temperature) leading to lower the cooling rate, that means a compromising now working between the reinforcement of α-grains with the directional eutectic growing and the grain coarsening resulted from a long time of solidification.

As a result, the activities of diffusion contributions take the priority in growth and enhancing also the grain refinement of the resulted microstructure to some extent. The orientation are now more easy to guided due to the long time maintaining at the liquid state and the concentration of heat flow in uni-direction (i.e. Y-axis)

3.4 Tensile, Compression & impact toughness Properties

Figures (5 and 6) shows accumulative diagram of the stress- strain curves in tension and compression of the samples produced at three conditions adopted in this work. Different behaviors were obtained as shown. In the case of free mold isolation, the behavior seems to be very close to the behavior of brittle material in each type of loading (i.e. tension and compression).

The reasons behind such behavior are:

1. Much micro-segregation in solid solution state.
2. Irregular distribution of primary silicon due to the low cooling rate across the material during the solidification process.
3. At, this conditions of solidification, where the cooling rate is low, the gas porosity nucleates and grows as expected (i.e. no degasser added).

Taking into consideration that the material is not homogenized or heat treated (i.e. as cast condition).

Compression results as shown in figure (6) for this case, shows that, the material was starting to yield at lower stresses (i.e. 392 Mpa), and when the applied stresses reach the value of (838 Mpa), the strain becomes (44%). These values give an indication that the material is week under such loading comparing with the material produced under the other conditions of solidifications. Impact toughness of this alloy mainly depends on shape, size, distribution of α-Al grains and eutectic silicon morphology. The value of absorbed energy is the average of three test samples manufactured from single casting.

The absorbed energy of the samples of free mold insulation conditions is (1.8 Joule). This value is characterized to be very low (i.e. the material is classified as a brittle material). The surface of fractured samples shows a rough surface due to the large grains in the alloy and the irregular distribution of eutectic phase. In addition the micro-segregation affects by make a poor interference bonding between the matrix and the segregated material (which are aluminum and silicon oxide mixed with the second phase). The irregularity of the little grown eutectic phase with the large grain size of matrix induces poor ductility to the cast material.

Figure (3) as it was stated above shows, the key of how the microstructure has changed along the y-axis of solidified ingot. This microstructure affects directly the mechanical behavior of material produced according to this condition.

Tensile test have been conducted only in section (d) according to figure (3) in the case of (sand, glass wool isolation mold), keep in mind that the tensile specimen need at least (100 mm) long of ingot. The tensile test results shows a clear improvement in comparassion with the case of free mold isolation conditions, the ultimate tensile strength has been improved, compares will be done according to the fracture strength that required for each specimen. Compression results (see figure 6) shows the beginning of material yielding at higher stresses (i.e. 415 Mpa), and when the applied stresses reach the value of (838 Mpa), the strain becomes (33%). These values give an indication that the material becomes stronger under such loading comparing with the material produced under the conditions of free mold isolation solidification.

1. It is known that, the behavior of the investigated alloy under the conditions of free mold isolation is almost brittle behavior.
2. Figure (5) shows a clear improvement in tensile properties. The reason behind such improvement is the development of grown eutectic phase firstly (i.e. it becomes flaky-shape with an improved length) and secondly its better orientation in the direction of y-axis (i.e. solidification axis).
3. This behavior is so expected due to the high cooling rate at the bottom end of the mold and also due to the grain refinement of fast cooling part of ingot at the area close to the bottom end.
4. Now, as the solidified ingot have sectioned away from the bottom , the tensile properties have decreased continuously until it reaches a very close values of the case of free mold isolation conditions.
5. The better grown and uni-directed eutectic phase plays as an in-situ fiber which is the reason behind such indicated reinforcement in the alloy under investigation.

In order to asses the toughness of the produced ingots or samples, an impact tests are conducted according to the specified section that indicated previously in section (A). Now, if a comparison have made between the impact toughness data at section (A) of the conditions above and the results obtained from the impact test of the conditions of free mold insulation, one can conclude that a noticeable development have occurred at this conditions of solidification. The energy absorbed by the sample at section (A) is jumped from (1.8 Joule) in the case of free mold insulation conditions to be (2 Joule) in case of sand mold insulations.

The reasons behind such improvement could be summarized as follows:

1. Noticeable elongation in the grain structure at the section (A), where the cooling rate is high.
2. Better orientation of grown eutectic phase in the direction parallel to the required solidification axis.
3. Less interfacial energy between the grown phase and the matrix.

The flaky shapes eutectic phase concentrate the stresses at the tips of the phase that enhancing the fracture of specimens, so that the efforts have been directed to get continuous fiber phase instead of discontinuous. The response of produced composite material now that reinforced by this manner to the multi-types of loading through the mechanical properties testing is different now. Key of how the microstructure has changed along the y-axis of solidified ingot. This microstructure reflects directly the mechanical behavior of material produced according to these conditions.

In the case of glass wool mold isolation, a clear improvement in comparassion with the case of free mold isolation conditions. Compression results shows the beginning of material yielding at higher stresses (i.e. 426 Mpa), and when the applied stresses reach the value of (838 Mpa), the strain becomes (31.5%). These values give an indication that the material becomes stronger under such loading comparing with the material produced under the conditions of free mold isolation solidification.

1. The reason behind such improvement is the development of grown eutectic phase firstly (i.e. it becomes flaky-shape with an improved length) and secondly its better orientation in the direction of y-axis (i.e. solidification axis).
2. This behavior is so expected due to the high cooling rate at the bottom end of the mold and also due to the grain refinement of fast cooling part of ingot at the area close to the bottom end.
3. Now, as the solidified ingot have sectioned away from the bottom , the tensile properties have decreased continuously until it reaches a very close values of the case of free mold isolation conditions.
4. The better grown and uni-directed eutectic phase plays as an in-situ fiber which is the reason behind such indicated reinforcement.

In order to asses the toughness of the produced ingots or samples, an impact tests are conducted according to the specified section that indicated previously in section (A). The tests shows a noticeable improvement have documented in the case of (glass wool mold insulation conditions) rather than the cases of free mold insulation conditions and sand mold insulation conditions., one can conclude that a noticeable development have occurred at this conditions of solidification. The energy absorbed by the sample at section (A) in this case (i.e. glass wool mold insulation condition) is jumped to be (2.5 Joule). The reasons behind such improvement could be summarized as follows:

1. Noticeable grain elongation at the section (A), where the cooling rate is low comparing high compared with the case sand mold insulation conditions and this because of the less of thermal conductivity .

2. Very better orientation of grown eutectic phase in the direction parallel to the required solidification axis.

3. The interfacial energy between the grown phase and the matrix in this case is less from the above two cases.

4. Conclusions

From above the following can be concluded:

1. The microstructure of Al-Si eutectic alloy affects directly by method in which the alloy can solidify.
2. It is possible to nucleate and grow the eutectic phase in Al-12%Si alloy by isolating the mold by which the molten alloy has poured from all sides and permitting heat escape from one side.
3. Three conditions of solidification have been used through a special solidification unit that designed and manufactured to ensure the uni-directional solidification of investigated alloy. These conditions based on using multi-types of insulation materials around the unit mold.

4. The first conditions based on no using of any insulation material with no water flow through the solidification unit didn't enhance the elongation and direct the eutectic phase that in turn gives poor mechanical properties.
5. The using of dry sand as insulator enhance the elongation and direct the eutectic phase in good percentage to the specified direction that in turn gives a better mechanical properties than that in the condition number one.
6. The letter insulator was the glass wool, which gives better mechanical properties by enhancing the growth of eutectic phase in uni-direction.
7. The microstructures of alloy generally consist from an α-matrix (aluminum) and eutectic phase which is becomes elongated and flaky when the solidification becomes uni-directionally.
8. The flaky shape of microstructure affects the impact toughness according to the direction of test.

Table (1)
Average chemical composition analysis of the Al-Si alloy in this work.

Element	Si	Fe	Cu	Mn	Mg	Cr
wt%	12.0000	0.5532	0.0752	0.0721	0.0053	0.0021
Element	Ni	Zn	Pb	Sn	Ti	Al
wt%	0.0101	0.0042	0.0035	0.0040	0.0028	Bal.

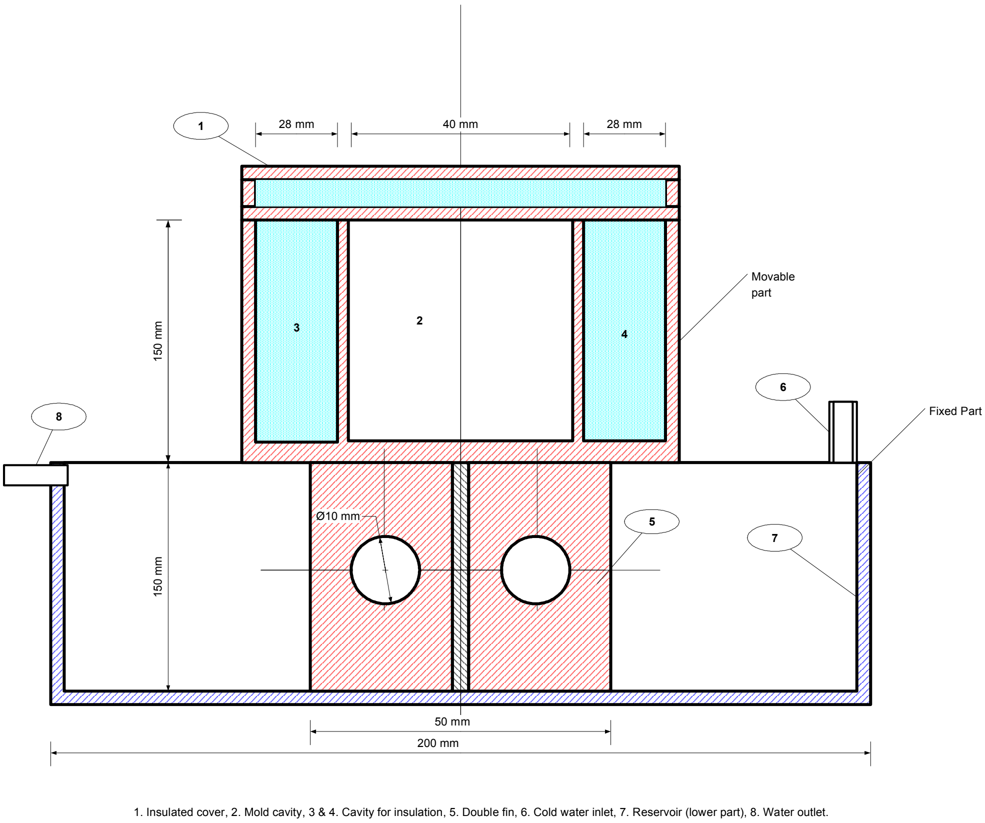

Figure (1).
A schematic diagram of the uni-directional solidification unit.

Table (2)
Adopted solidification conditions

Set of sample no.	Solidification condition		Microstructure shown in
	Mold insulation type	Cold water flow	
1	Free	Without	Fig.(3-a)
2	Dry sand	With	Fig.(3-b,c,d)
3	Glass wool	With	Fig.(3-e,f,g)

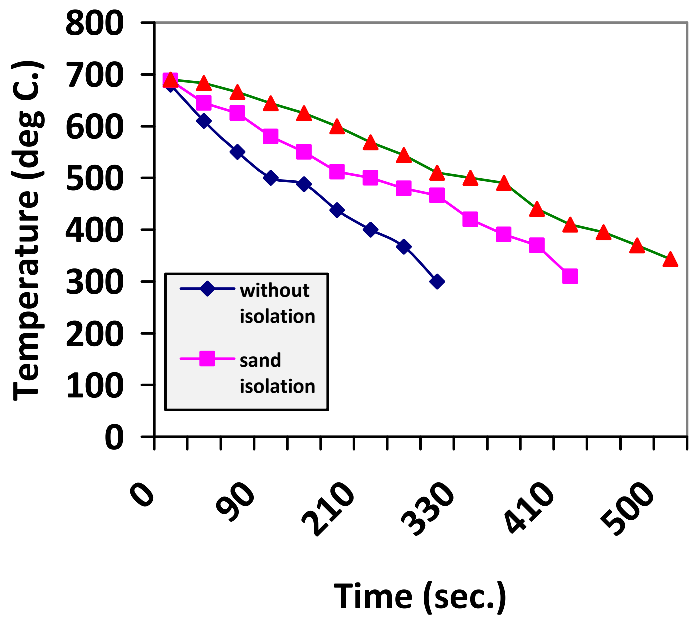

Figure (2)
Accumulative diagram shows the cooling curve at
(three conditions adopted in table (2)).

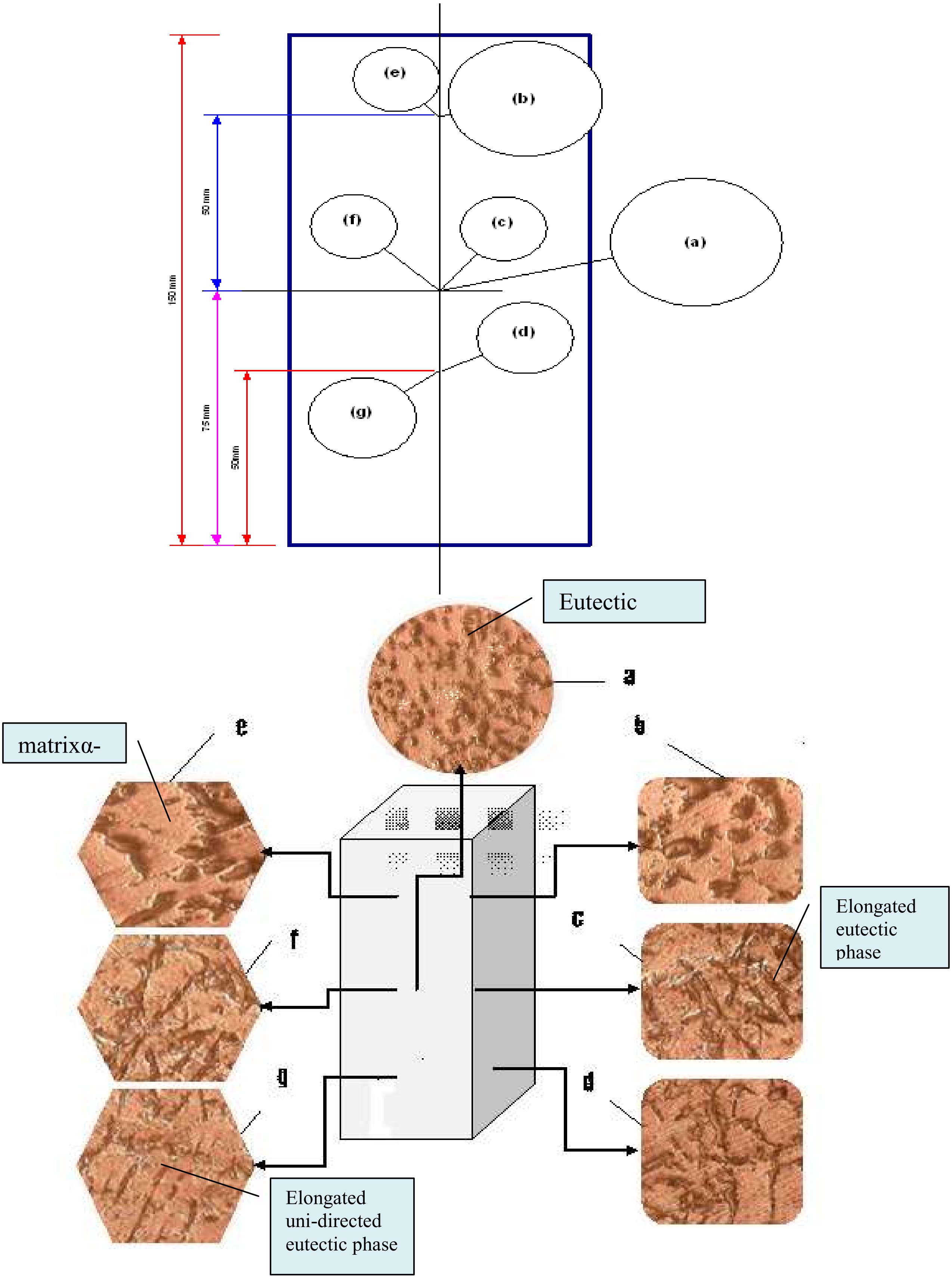

Figure (3): A schematic diagram of the resulted microstructure for each case remembered in table (2), (constant magnification 350X for each samples)

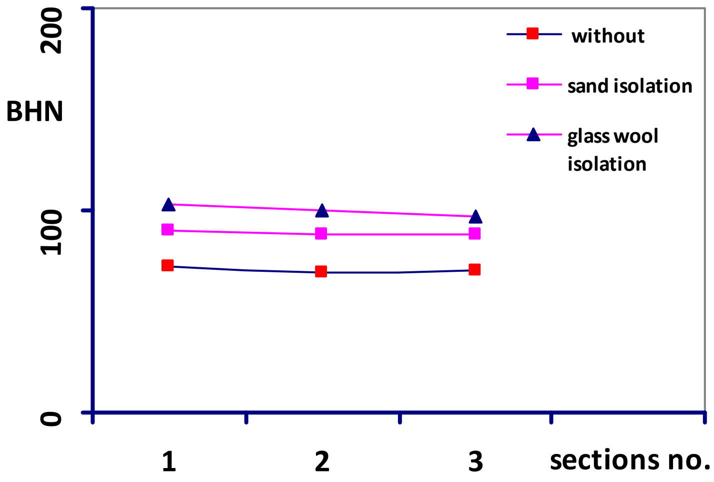

Figure (4)
Accumulative diagram of the Brinell harness survey at (three conditions adopted in table (2))

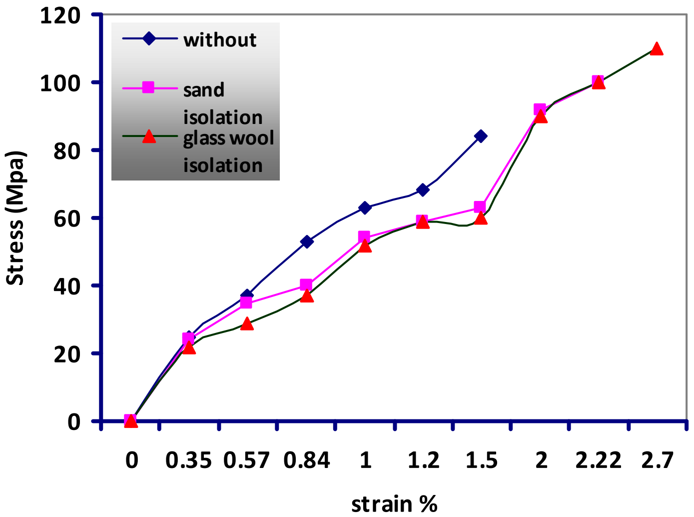

Figure (5)
Accumulative diagram of the stress-strain diagram of the Al-Si eutectic alloy at (three adopted conditions in table (2)).

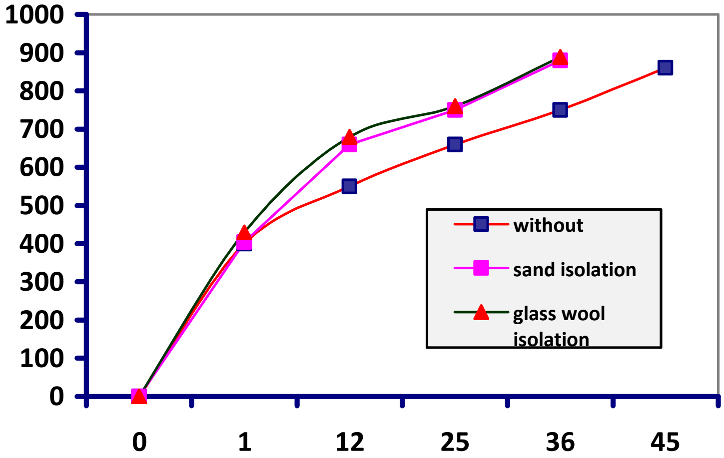

Figure (6)
Accumulative diagram of the stress-strain curve under compression load at (three conditions adopted in table (2)).

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