
Production of ZA-27 Alloy by New Rheocasting Process.

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Abstract

The present work encompasses the grains refining of microstructure of Zn-Al alloy (ASTM B669 ZA-27) ingots without addition of refining agents or using stirring, that is, by using the New Rheocasting (NRC). AISI 316 stainless steel mould is employed with inclination angle of 75° and 1.2 V/A ratio. The pouring temperatures are 532 °C, 522 °C, and 502 °C, while the quenching occurs at different temperatures. The examination shows that all NRC ingots have microstructure of refined equiaxial grains in the range of 27-36 μm, while the percentage of volume fraction of α-Al phase was varied from 0.56 to 0.76. The value of circularity was in the range of 1.33-1.65. The NRC ingots achieved less coarsening kinetic than critical value which shows that there is a limited increase in the grain size and coalescence of reheating. Tensile strength, Yield strength, and Elongation of ZA-27 alloy which was made by NRC process, increased to 18%, 11%, and 32% respectively compare to Gravity Die Casting (GDC) ingots due to formation of equiaxial grains along all the cross section in addition to smaller grains size.

Keywords: New Rheocasting, Zn-Al alloy, Pouring Temperature, Quenching Temperature, Equiaxial Grain, Mechanical Properties.

Introduction

The concept of new rheocasting is based on forced homogeneous nucleation of α-phase, which continues to grow in globular shape due to controlled cooling. Fig. (1) Shows a schematic diagram of the process, indicating the essential process parameters. When the melt touches the wall of the steel crucible its temperature immediately drops into the semi-solid range and nucleation of α-phase starts. The melt must not be superheated excessively; otherwise the nuclei will be destroyed again. Concerning the ideal volume fraction of solid before casting, some experimental work has yet to be done. While in classical thixocasting a very stable slug is requested for handling purposes, this is not required in NRC, at least for this reason. In NRC the slurry is kept in a steel crucible and may well contain less than 0.50 solid fractions at the time of transfer into the sleeve of the squeeze casting machine.

Since 0.5 solid fraction yielded best results in classical thixocasting the first development work in NRC concentrated on this ratio as well [1-4]. Now matter how much solid fraction was present in the slug at the beginning of the shape casting process, the slurry should become fluid with low viscosity under limited shear stress to achieve excellent flow and die filling properties. This means that the α-phase should have a shape as round as possible and be interconnected with α-bridges, which can be torn apart by shear stress in the ingate area of the die. After solidification bridging of the α-particles would again be advantageous for improved elongation and fatigue properties [5-8].

Experimental Procedure

To study the microstructure of NRC process, air cooling was replaced by water quenching from the required temperature to insure the preventing of the

Table (1) Chemical composition of ZA-27

Chemical Composition (wt %)	Al%	Cu%	Mg%	Fe%	Cd%	Pb%	Zn %
Nominal Chemical Composition	25-28	2-2.5	0.01-0.02	0.1	0.003	0.004	Rem.
Actual chemical composition	26.1-26.3	2.14-2.27	0.013-0.017	0.067-0.070	0.0013-0.0025	0.0011-0.0033	Rem.

solid phase growth and the refining of the second phase to produce billet with equiaxed structure.

The cooling of the liquid metal within freezing range required a mould metal with two main conditions; **(I)** Giving low cooling rates during liquid/solid range to offer enough time for quenching in water at the temperature corresponding to the required volume fraction of the solid, and **(II)** Enduring heat within the pouring temperature range without the possibility of molten metal contamination by the elements of the mould metal. AISI 316 stainless steels has relatively low thermal conductivity as compared to other steel types in addition to work at temperature reaching 850 °C ,i.e. fulfilling the two above conditions. The billet was selected with Volume to Surface Area ratio (V/A) equal to 1.2 [9] with dimension of 6x6x12 cm and mould wall thickness of 2.5 mm.

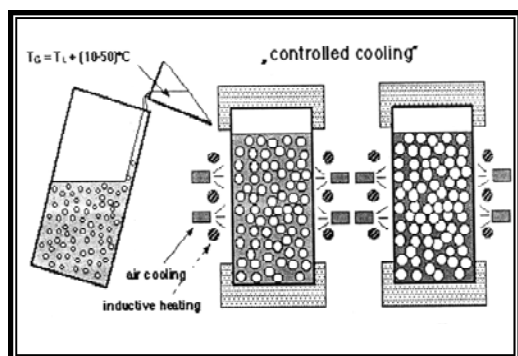


Fig. (1) The NRC processing steps (ladling into a steel crucible for nucleation and growth of globular -particles, controlled cooling then transfer into a vertical squeeze casting machine).

The ZA-27 was selected to illustrate the possibility of producing it by NRC process. The ZA-27 alloy has chemical composition shown in table-1 and a melting point of 492 °C. The alloy was produced with pouring temperatures of (502 °C, 522 °C & 532 °C) that is equal to " $T_m+10-50$ °C", where T_m is the melting temperature of the alloy.

For comparing the structures resulted from NRC process, two alloy ZA-27 castings were produced in mould made of AISI H12 of dimensions 6x6x12cm, with wall thickness of 25 mm in two cases ; **(I)** Pouring at 550 °C without grain refinement addition . **(II)** Pouring at 550 °C with grain refinement addition (Al-10Ti) immediately before casting.

Electrical radiation furnace type was used .The furnace charged from ingots of electrolytic zinc, pure aluminum and aluminum master alloys. A thermometer with thermocouple type chromel-alumel (K-type) covered by a hastalloy was employed to measure the molten metal temperature with an accuracy ± 1 °C. On the other hand, the temperature of the metal inside the mould was measured using two thermocouples K-type with a diameter of 1.5 mm inserted to a distance about 1.5 mm & 30 mm into the mould to determine the cooling rate and the temperature at which a quenching carried out. A movable fixture was fabricated to enable the selection of 75° as a pouring angle as shown in Fig-2. This angle improved the microstructure and the

ability of achieving equiaxed structures starting from the casting wall to the center, so, increasing the possibility of taking place of isotropic structure [9]. Specimens of Rheocasting alloy ZA-27 were selected to be reheated at 410 ± 2 °C for periods of 5 & 10 min. to measure K-factor [1] and compare it with the other casting processes.

Coarsening Kinetics can be determined by using the following equation:

$$D^3 - D_0^3 = Kt \quad \dots\dots\dots (1)$$

Where:

D-current grain size μm .

D₀-initial grain size μm .

t-time sec.

K-coarsening kinetics $\mu\text{m}^3/\text{sec}$.

The measurement of Dendrite Arm Spacing (DAS) was taken place by the intersect method [10] (Fig.3). In addition to, lineal intercept technique was also employed to measure the grain size.

Results and Discussion

NRC as mentioned, was included the pouring of a molten metal at temperature " $T_m + 10 - 50$ °C" on the wall of an inclined mould to achieve two principle aims; **(I)** increasing the contact area between molten metal and mould, that gives good opportunity for crystals formation on the wall [11]. **(II)** Increasing the distance of molten metal flows which will help in increasing the possibility of separating the freezing crystals from the mould wall. So, it is necessary to determine the billet dimensions, quenching temperature and mould inclined angle firstly.

Effect of billet dimensions

Equation(1) shows that the weight of casting is the most important factor affecting heat generated during freezing in addition to pouring temperature [12];



Fig (2): Schematic of steel stainless mould and fixture

$$q = w [H + C_p (T_c - T_i)] \quad \dots\dots 2$$

Where:

q = heat extraction (J).

W = weight of casting (kg).

T_c = pouring temperature (k).

T_i = temperature at the mould interface (k). assumed to be equal to freezing temperature of the metal.

C_{PL} = specific heat of liquid metal (J/kg.k).

H = latent heat of fusion of the metal (J/kg).

The increasing of casting weight and pouring temperature with constancy of C_{PL} & H of the metal or the alloy will increase the heat extraction (q) and then increased the solidification time [12];

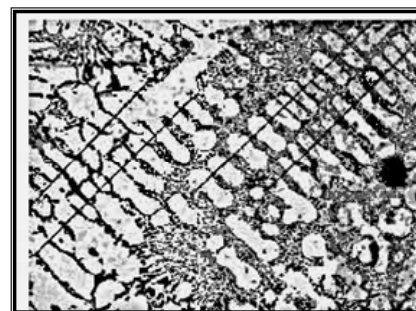


Fig (3): Measuring of Dendrites Arm Spacing

$$t_c = \frac{w[H + C_{pl}(T_c - T_f)]}{1.128 A \alpha_m (T_i - T_o)} \dots\dots\dots 3$$

Where:

T_f = final solidification temperature (k).

α_m = heat diffusivity of the mould material which itself equal to; $\sqrt{k\rho C_p}$

Where:

k = Thermal conductivity.

ρ = density.

C_p = specific heat.

These are giving large opportunity for dendrite growth and increasing Dendrite Arm Spacing (DAS). It is necessary to adopt the three factors ; mould condition , pouring temperature & liquid metal movement , to refine the casting structure , in addition to controlling of casting dimensions (modulus or shape factor V/A) and obtain a suitable freezing time for quenching from the temperature corresponding the volume fraction of the required solid.

On the grounds of, we selected casting with dimension 6x 6x12 cm of volume 432 cm³ and surface area of 360 cm² with total weight of 2600 gm to grant equal to 1.2.

Selection of quenching temperature

Equation (3) illustrates the direct relationship of local weight fraction solid to temperature in the liquid-solid zone [12].

$$f_\ell = \left(\frac{T_M - T}{T_M - T_l} \right)^{\frac{1}{1-k}} \dots 4$$

Where:

T_M = melting point of pure solvent.

T_l = melting point of alloy of composition C.

k = constant partition ratio.

T = temperature in the liquid-solid zone.

f_l = weight fraction liquid in liquid–solid zone.

It is clear that the quenching temperature at liquid –solid zone for ZA-27 alloy is 410 °C to obtain 0.5 volume fraction α-Al phase.

For guarantee to achieve equiaxed structure across casting section it is necessary considering the reducing of cooling rate at casting wall corresponding to centre, so, it required to select the temperature of casting wall for quenching to attain the desired structure.

Cooling Curves

From Fig. (4), the increasing of superheating temperature increases the temperature different between the wall and the casting centre .While the difference arrives to about 77 °C after 22 second, becomes 40 °C at 60 second for ZA-27 pouring at 532 °C .The reducing of pouring temperature to be close of melting temperature, assisting to decrease the temperatures different between the wall and centre of what providing the homogenous of primary phase volume fraction across casting cross section. In addition, it lowers the required time for solidification and decreasing the occasion of primary phase (α-Al) grain growth.

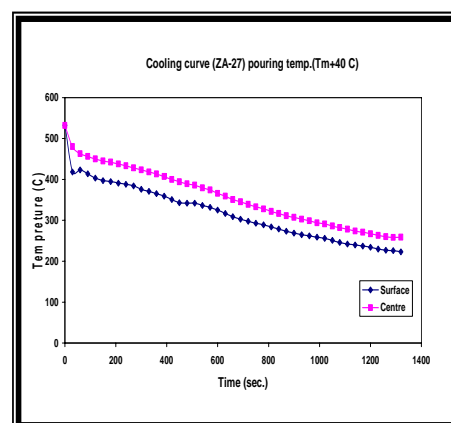


Fig. (4); Cooling curve of ZA-27 pouring

Effect of mould inclined angle:

The effect of mould inclination on the microstructure of Al-7%Si was studied at different angles (15°, 30°, 45°, 60°, 75° and 90°). It was found that the 75° mould angle is the best to be capable of attaining equiaxed grains across the casting cross section, as well as, increasing the α -Al volume fraction, leading to improve the ductility and isotropic structure [9]. The flowing of molten metal on the mould wall with the mentioned angle attributes to the high heating loss and the separation of nuclei from mould wall and growing as a separated grain [1].

Gravity Die Casting (GDC) of ZA-27 alloy:

Two casting were produced from alloy ZA-27 by GDC process with 1.2 V/A ratio, where they poured at a temperature

The Fig (5): Microstructure of GDC producing with out grain refinement.

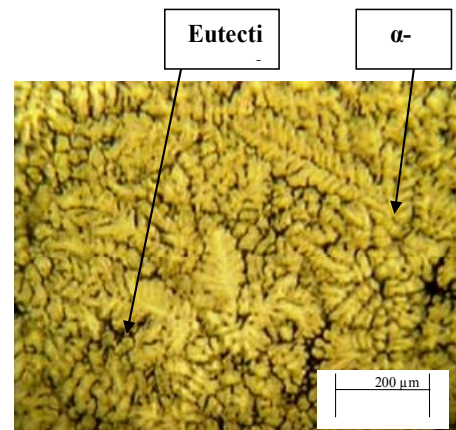
of 550 °C at an angle of 90° in AISI H12 steel mould. Grain refinement alloy (Al-10Ti) was added to one casting.

microstructure demonstrated was dendrite completely for both cases starting from the wall to the centre as shown in Fig-5 with a finer DAS (16 μ m) for the casting to which grain refinement was added (Fig.6).

Rheocasting of ZA-27 alloy;

I. Pouring at 532 °C:

The pouring at angle of 75° and quenching from 440 °C is accompanied by an uniformity in equiaxed grain size (Figs.7,8) ranged between 31-33 μ m with 0.6 α -Al volume fraction along the cross section of the casting.



The Fig (5): Microstructure of GDC producing with out grain refinement.

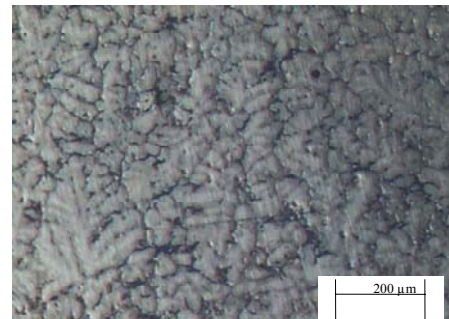


Fig (6): Microstructure of GDC producing with grain refinement of Al-10Ti

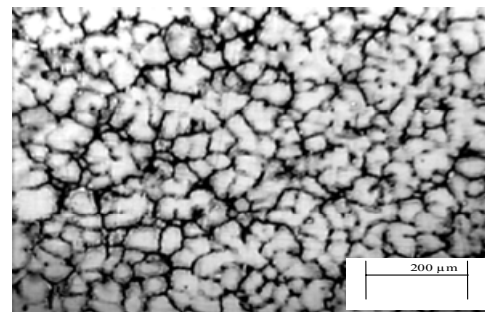


Fig. (7): Microstructure of NRC pouring at 532°C and quenching at 440 °C, (a) at 5 mm, (b) at 20 mm from cast wall

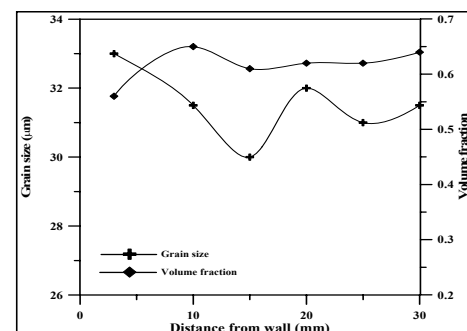


Fig (8): Variation of grain size and volume fraction of α -Al with distance from casting wall pouring at 532 °C and quenching at 440 °C

It was noticed that when quenching temperature was reduced to 410 °C, the structure was equiaxed too, ranged from 30-36 μm with α-Al volume fraction of 0.62 (Figs.9,10). The mean of diameter of equiaxed grains is still within the range of 30-36 μm and 0.59 volume fraction (Figs.11,12) when more reducing the quenching temperature to 396 °C. The reduction of quenching temperature by 30°C and 44 °C has effect to some extent on grain size or volume fraction of primary phase.

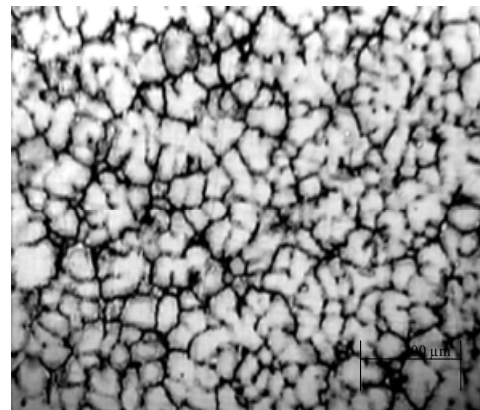


Fig. (11); Microstructure of NRC pouring at 532 °C and quenching at 396 °C, at 20 mm from casting wall.

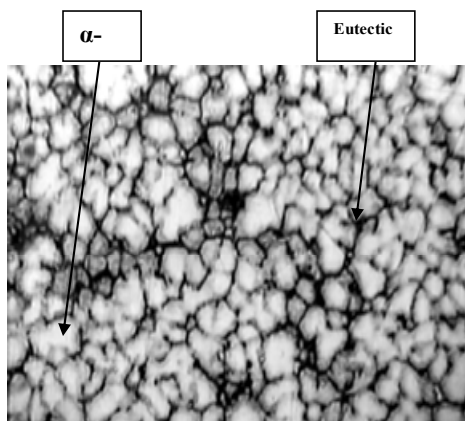


Fig. (9); Microstructure of NRC pouring at 532 °C and quenching at 410 °C, at 20 mm from casting wall

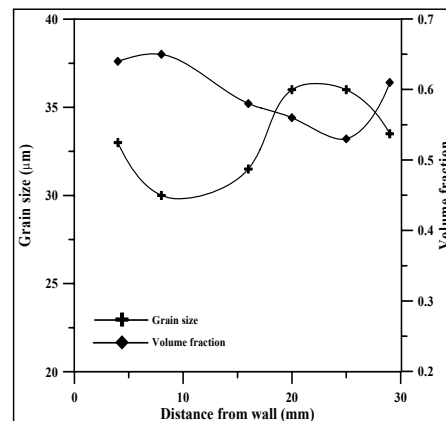


Fig. (12); Variation of grain size and volume fraction of α-Al pouring at 532 °C and quenching at 396 °C, With distance from casting wall.

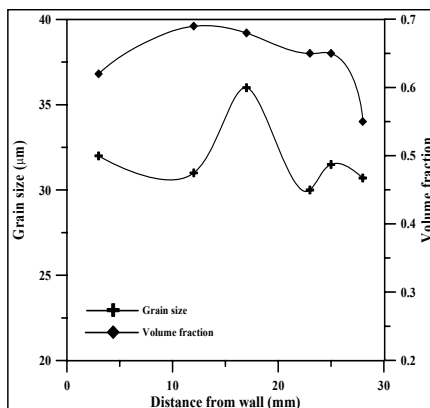


Fig. (10); Variation of grain size and volume fraction of α-Al with distance from casting wall, pouring at 532 °C and quenching at 410 °C

II. Pouring at 522 °C:

The pouring at 522 °C and quenching from 440 °C decreased the diameter of equiaxed grains to 27-31 μm with primary phase of 0.66-0.68 as shown in Figs.13 and 14.

Reducing pouring temperature by 10 °C promoted to lowering the average grain size less than 30 μm with increment of volume fraction along cross section. With quenching from 410 °C, average grain size lowering to 28 μm (Figs.15) but volume fraction of primary phase is still

about 0.66. More reducing quenching temperature to 396 °C not associated to some extent with decreasing grain size (28-34 μm) or volume fraction (0.62-0.74) (Figs.16, 17).

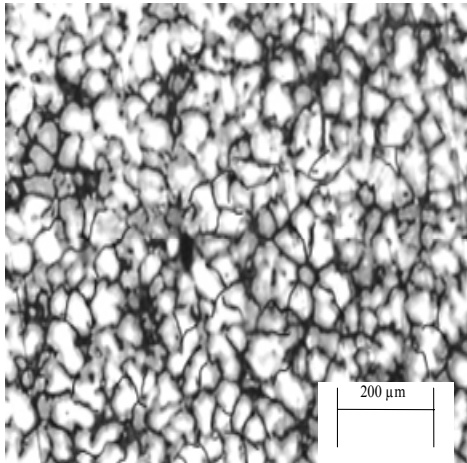


Fig. (13); Microstructure of NRC pouring at 522 °C and quenching at 440 °C , at 20 mm from casting wall.

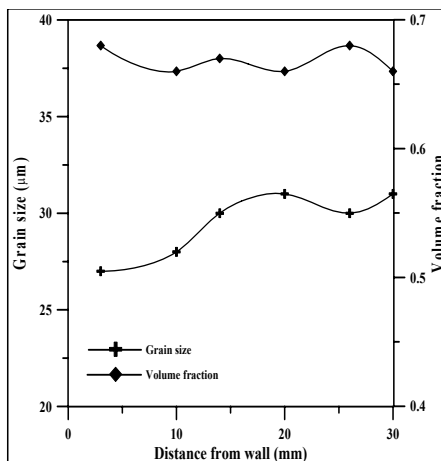


Fig. (14); Variation of grain size and volume fraction of α -Al pouring at 522 °C and quenching at 440 °C with distance from casting wall.

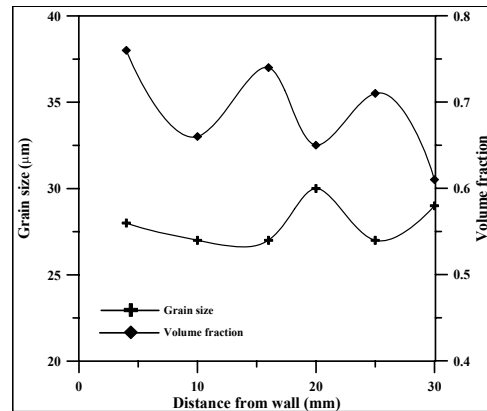


Fig. (15); Variation of grain size and volume fraction of α -Al with distance from casting wall pouring at 522 °C and quenching at 410 °C

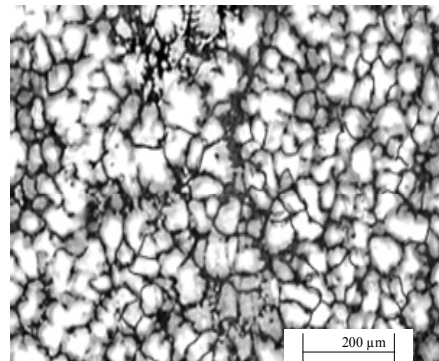


Fig. (16); Microstructure of NRC pouring at 522 °C and quenching at 396 °C , at 20 mm from casting wall

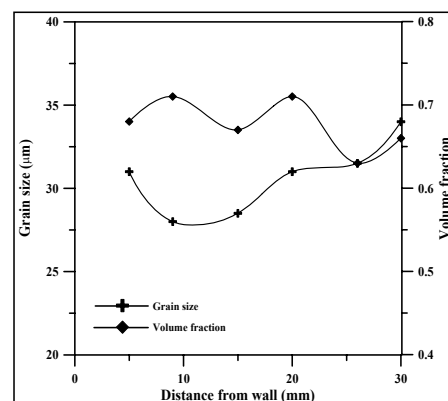


Fig. (17); Variation of grain size and volume fraction of α -Al with distance from casting wall , pouring at 522 °C and quenching at 396 °C.

iii. Pouring at 502 °C:

Reducing of pouring temperature to 502 °C has no distinct affect on grain size or volume fraction when quenching from 440 °C (Figs.18,19). Quenching from 410 °C accompanying with slightly decreasing of grain size (27 μm) and constancy of volume fraction (0.56-0.67) (Figs.20,21). Supplementary reduction of quenching temperature to 396 °C donate equaxied grains also with the same approximately average volume (28-31 μm) and volume fraction more than 0.5 (056-.061) (Figs.22,23).

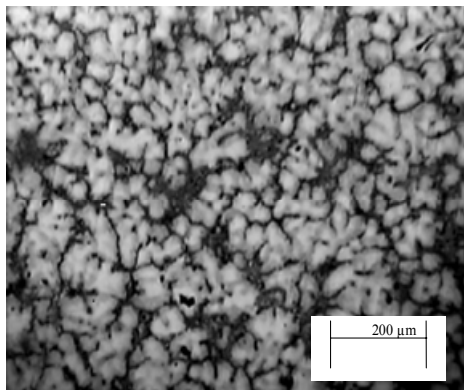


Fig. (18); Microstructure of NRC pouring at 502 °C and quenching at 440 °C, (a) at 5mm, (b) at 20 mm from casting wall

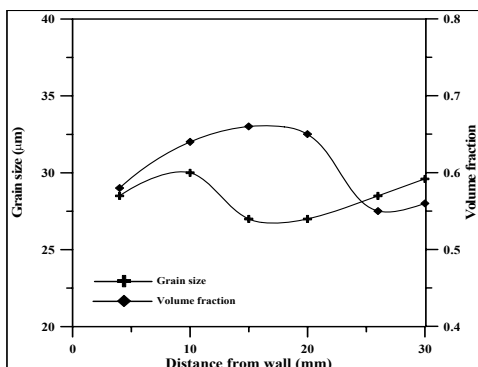


Fig. (19); Variation of grain size and volume fraction of α-Al with distance from casting wall, pouring at 502 °C and quenching at 440 °C

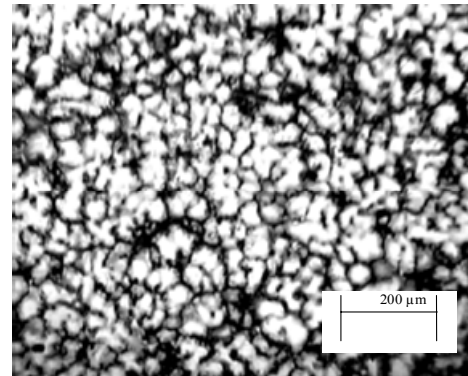


Fig. (20); Microstructure of NRC pouring at 502 °C and quenching at 410 °C, a. at 5 mm, b. at 20 mm from casting wall

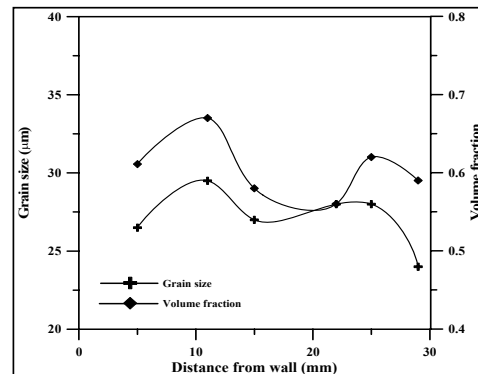


Fig. (21); Variation of grain size and volume fraction of α-Al with distance from casting wall pouring at 502 °C and quenching at 410 °C

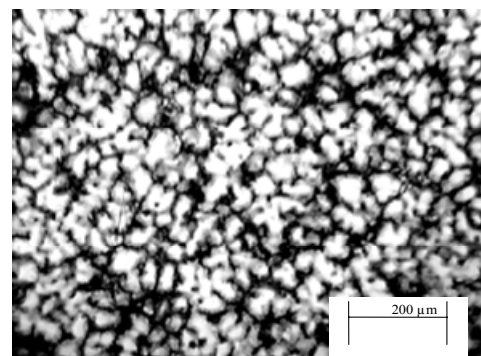


Fig. (22); Microstructure of NRC pouring at 502 °C and quenching at 396 °C, a. at 5 mm, b. at 20 mm from casting wall

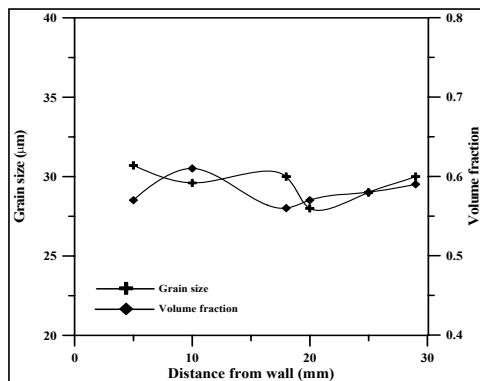


Fig. (23); Variation of grain size and volume fraction of α -Al with distance from casting wall pouring at 502 °C and quenching at 396 °C

The Circularity:

Circularity was measured by grain size program to quantify the effect of quenching temperatures on the α -Al grain shape. Its values approached (1) at all quenching temperature with range 1.35-1.65. Normally circularity (shape factor) is greater than (1), however, in case of fully spherical grain is equal to (1) and for dendrite microstructure the circularity is greater than (3) and thixotropic state cannot achieved, while with circularity less than (2) that is typical precursor material. The closer circularity approach (1) the more the rheological behavior improves in semi-solid state. This shows that the production of ZA-27 by NRC gave grain shapes closer to spherical which would reflect positively on later forming processes in the reduction forming stresses, as well as, improving the final product specifications [1].

Reheating of as-cast NRC ZA-27

To show the effect of reheating of as-cast NRC ZA-27 on the coarsening of α -Al grains and grain coalescence, specimens from the casting of pouring temperature 522 °C and quenching at 410 °C were heated to 410 °C \pm 2 for soaking times 5 and 10 min.

It was found that the coarsening kinetics for 5 min specimen calculated by the equation of volume diffusion controlled coarsening (Equation-1) equal to 78.48 $\mu\text{m}^3/\text{sec}$. which less than the critical value (148 $\mu\text{m}^3/\text{sec}$.) [1]. It emphasized that the increase in grain size and their coalescence are limited. The grain size increased from 28 μm to 42 μm after heating 10min. while the volume fraction increased from 0.68 to 0.74.

Mechanical properties of ZA-27

The tensile strength of NRC castings pouring at 532 °C and quenching at 410 °C, for example, was 513 MPa with yield strength of 418 MPa and elongation 8%. It can be seen when comparing NRC castings with GDC castings as given in table-2, there is an increase equal to 18% in tensile strength, 11% in yield and 32% in elongation which is due to the refining of the grains and their equiaxed shapes.

Table (2); Mechanical properties of ZA-27

Casting process	NRC	GDC
Tensile Strength (Mpa)	513	418
Yield Strength (Mpa)	438	387
Elongation %	7.1	4.8
HB	137	113

Conclusion

1. It is possible to produce ASTM ZA-27 alloy by NRC process.
2. V/A of 1.2 and pouring temperature of $T_m+10-50$ °C is provided equiaxed primary phase at all quenching temperature.
3. The variation of pouring quenching temperatures is associated with small variation in grain size or volume fraction of α -Al.

4. The coarsening kinetics of NRC castings is less than the critical value, so that, the increasing in grain size and their coalescence is limited when reheated.
5. The circularity of ZA-27 alloy at all quenching temperatures ranged from 1.35 to 1.65.
6. Mechanical properties, σ_u , σ_y & elongation are increased by 18%, 11% and 32%, respectively, comparing with GDC ZA-27 alloy.

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بەرھەم ھینانی دەرشتە توتیا- فافۆن ZA-27 بەرئیگای داریژانی ھەلقولان

عدنان نەمە عبود ، گاهر صالح حیبب ، کولیی تەکنیکی \ بەغدا

پوختە

نەم لیکۆلینە و ھەبە بریتی یە لە بچوک کردنە و ھەبە دەتکۆلەکانی پیکھاتە میکرۆسکۆپی دەرشتە توتیا- فافۆن { ASTM B669 ZA-27 } یی زیادکردنی یاریدەدەرەکانی بچوک کردنە و ھەروەھا بەبێ سووراندنە و ھەبە کارھینانی نوێترین رینگاکە داریژانی ھەلقولانە. یۆ نەم ھەبەستەش قاتیکی دروست کراو لە ستیلی ژەنگ ھەنەھین جۆری AISI 316 بەکار ھینراوە بە گۆشە یەکی لار بەرکە (75 °) و ریزە قەبارە داریژاوەکە بۆ ھەبەری ھەبەکانی دەگاتە 1:2 . تۆینراوەکە لە پلەکانی (502 °C, 522 °C, 533 °C) دا داریژاوە و لە پلە گەرمی جیاوازدا سارد کراوەتە و . تاقیکردنە و ھەبەکان دەریان خستوو کە داریژاوەکانی داریژانی ھەلقولان دەتکۆلەکانی ھەبەکان زۆر و ھەبەبارەکانیان لە نۆیان { 27-36 μm } دا یە . کاتیکی ریزە قەبارە تە و ھەری α-Al لە نۆیان (0.76-0.56) دا یە و ھەری خریوونە و { 1.65-1.33 } یە . داریژاوەکانی داریژانی ھەلقولان تۆنای زۆر بوونیان کە مەترە لە بۆر ناچیکرێنە مەش دەریدەخات کە زیاد بوونیک دیاری کراوە یە لە قەبارە دەتکۆلەکان و ھەروەھا لە تۆنای بەبە کدا لکان لە کاتی دووبارە گەرم کردن دا بەرگری راکیشان و . بەرگری ملدان و داریژاوەکانی دەرشتە ZA-27 کە بە داریژانی ھەلقولان دروست کراون بەرژە 1.8% , 11% , 32% یە کە ئە ھوای یەکی زیادیان کردوو ئە چا و داریژاوەکانی قالیبە کانزایی یەکان بە ھۆی دروست بوونی دەتکۆلە ھاوشیو بە داریژایی یانە بەرگە داریژاوەکانی داریژانی ھەلقولان .

أنتاج سبيكة زنك- المنيوم (ZA-27) بطريقة السباكة التذقية

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الخلاصة

اشتمل البحث على تنعيم حبيبات البنية المجهرية لمصبوبات زنك-المنيوم (ASTM B669 ZA-27) دون اضافة عامل تنعيم أو تدوير المنصهر باستعمال طريقة السباكة التذقية الحديثة. استخدم قالب مصنع من الفولاذ المقاوم للصدأ نوع (AISI 316) بزاوية ميل قدرها (75°) وبنسبة حجم مسبوكة الى مساحتها بلغت (1.2) . سكب المنصهر بدرجات حرارية (502 °C , 522 °C , 533 °C) وبرد من درجات حرارية مختلفة. أظهرت الاختبارات للمصبوبات ان لها حبيبات ناعمة تراوحت حجوما من (27-36μm) بينما بلغ الكسر الحجمي لطور (α-Al) من (0.56-0.76) وقيمة تكورية (1.33-1.65) . حققت مصبوبات السباكة التذقية طاقة تخشين أقل من القيمة الحرجة مما يظهر أن هناك زيادة محدودة في حجم الحبيبات وكذلك في الالتصاقية أثناء إعادة التسخين. زادت مقاومة الشد لمصبوبات السباكة التذقية مقارنة بمسبوبات السباكة في القوالب المعدنية بمقدار (18%) فيما زادت مقاومة الخضوع بمقدار (11%) وبنسبة مطيلية (32%) نظرا لتكون حبيبات ناعمة متساوية المحاور على طول المقطع العرضي لمصبوبات السباكة التذقية.