Effectiveness of Naphthalene in Grain Refinement of Commercially Pure Aluminum and Zinc Ingot Castings

Assifa M. Mohamad*

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Abstract

It is well established that the properties of cast metals are greatly improved by refinement of their grain size. The method employed in this study for the refinement of grain size of commercially pure aluminum and zinc castings is inoculation of naphthalene in powder form to the mould prior to pouring the molten metal. The results show that the addition of naphthalene remarkably suppresses the formation of columnar grains and refines the structure. Increasing the amount of naphthalene addition also minimizes and may eliminate the formation of the shrinkage cavity. Furthermore, the ability of castings for mechanical working increases as the naphthalene addition increases.

Keywords: grain refinement, aluminum and zinc castings, melt inoculation.

فـعّـالية مادّة النفثالين في تنعيم حبيبات صبات الألمنيوم والخارصين النقي تجارياً

الخلاصة

من المعروف أنّ خواص المعادن المسبوكة تتحسن كثيراً بتنعيم حبيباتها ، والطريقة المستخدمة في هذه الدراسة لتنعيم حبيبات مسبوكات الألمنيوم والخارصين النقية تجارياً هي إضافة مادة النفثالين على شكل مسحوق الى القالب قبل صب المنصهر المعدني. بيّنت النتائج أنّ إضافة النفثالين يقلّل كثيراً من تكوّن الحبيبات الطولية وينعّم بنية حبيبات المسبوكة ، كما أنّ زيادة كمية النفثالين المضافة تقلّل وقد تمنع كلّية تكوّن فجوة التقلص. إنّ قابلية المسبوكات للتشكيل الميكانيكي تزداد كذلك بزيادة كمية النفثالين المضافة.

Introduction

Metals and alloys usually solidify with coarse columnar grain structure under normal casting conditions and grain refinement is a common industrial practice. McCartney [1] has defined grain refinement as deliberate suppression of columnar grain growth in ingots and castings and formation of fine equiaxed solidification structure throughout the material. It is well recognized that grain refinement plays an important role in the determination of the properties of castings. This includes improvement of strength, finer and more homogeneous distribution of porosity and less probability of chemical segregation inside the casting.

In general, grain refinement can be achieved industrially in two ways. One way is to heat treat the castings but this is effective only in a few alloy systems. Refinement of the grain size during solidification is more extensively employed. The latter method can be

*Electromechanical Engineering Department, University of Technology/ Baghdad

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University of Technology-Iraq, Baghdad, Iraq/2412-0758

classified into two broad categories: control of nucleation by control of the casting conditions such as the temperature of the melt and the rate of cooling, or the use of inoculants [2-7] and application of physical disturbances, such as mechanical and electro-magnetic stirring [8], oscillation and vibration [9], and gas bubble agitation [10].

For castings of aluminum and its alloys, addition of titanium and boron, either singly or in combination, results in considerable grain refinement [2, 3, 5, 6]. Aluminum castings can be also refined by bubbling volatile halides such as $TiCl_4$ (boiling point 135 ˚C) or BCl_3 (boiling point 13 ˚C) or a mixture of the two through the melt with the aid of a carrier gas like nitrogen or chlorine [11]. Many types of self sinking tablets have been made available in the market, which are quite effective for the grain refinement of aluminum alloys. Cupini and Prates [12] introduced a simple method for refining the structure of titanium-boron treated aluminum ingot castings. The method consists basically of hexachlaroethane additions to the mould coating, which upon pouring of the melt, sublimes and results in gas bubble evolution during early solidification. This paper investigates the possibility of employing another volatile compound such as naphthalene, to refine the structure of ingot castings of commercially pure aluminum and zinc.

Experimental Procedure

The materials used were commercially pure aluminum and zinc supplied as small pieces. The chemical composition of the materials is shown in table (1). Top pouring ingot casting practice was employed. The charge was melted, brought up to the desired superheating temperature by resistance heating in a graphite crucible and subsequently cast into a mild steel cylindrical mould. Mould dimensions were: (47 mm inner diameter, 10 mm wall thickness and a height of 70 mm). A 1˚ taper being provided for easy removal of the ingot. The mould was open from both ends and hence prior to casting, the mould was placed on a steel plate 10 mm in thickness and sealed with a thermal material. The method used to incorporate naphthalene into castings was to place it in powder form at the base of the mould prior to pouring the molten metal.

For macrostructure examination, the ingots were cut in half longitudinally, and the surface of the section was grounded and polished in the usual manner. The etching solution was a saturated solution of sodium hydroxide for aluminum and a solution of 50 % hydrochloric acid with 50 % distilled water for zinc.

The percentage volume of equiaxed grains has been approximated by assuming the shape of the zone to be a solid cylinder. The volume of this cylinder has been calculated from the average diameter and height of the equiaxed zone at a longitudinal mid-section of the ingot.

Simple compression tests under a constant load of 150 KN were carried out to study the effect of the structure of ingots on their workability (expressed in terms of compressed height). The dimensions of the specimens for compression were 47 mm in diameter and 47 mm in height.

Results And Discussion

The effect of naphthalene in refining the ingot grain structure was studied with particular reference to the naphthalene fraction. High melt superheat of approximately 100 ˚C was incorporated since this would increase the tendancy of the formation of columnar grains.

Figures (1 and 2) show that the addition of naphthalene could remarkably refine the ingot structure of commercially pure aluminum and zinc, respectively. The effect of the percentage weight of naphthalene on the percentage volume of equiaxed grains in the structure is shown in figure (3).
More naphthalene fraction however was needed to refine commercially pure zinc. Full refinement of the structure was not achieved in this study even with the maximum naphthalene fraction used (2% for aluminum and 9% for zinc). It is anticipated that daubing the naphthalene powder on to the mould surface, instead of the usual method of placing it at the bottom of the mould, would have fully refined the structure.

Figures (1 and 2) also show that a large shrinkage cavity develops at the upper part of the ingot when casting without any addition of naphthalene for both aluminum and zinc. This is due to the contraction of the metal as it solidifies. Increasing the amount of naphthalene addition minimizes or even eliminates the shrinkage cavity.

Naphthalene, $C_{10}H_8$, vaporizes rapidly when it contacts the hot molten metal due to its low sublimation point (80 ˚C). This leads to the evolution of gas bubbles and thus agitating the bulk liquid, presumably during the early solidification process. At the same time, gas bubble agitation of the bulk liquid is expected to aid the removal of the pouring superheat to some extent from the top free surface. On the other hand, naphthalene vapor reacts with oxygen and it combusts as it reaches the melt surface, causing heat evolution in this zone and hence acting as a hot top to minimize or eliminate the shrinkage cavity.

In the aluminum and zinc ingots produced by the gravity die casting method adopted in the present work, solidification is expected to commence on the bottom surface of the mould with the formation of a thin solid skin and spread up the mould wall with time [13]. It is anticipated that these developments in the melt which occur very quickly would cause a pressure build-up in between the mould wall and this initial solid skin of the metal. A critical pressure value will be reached at which disintegration of the solid into numerous tiny crystals will take place. The tiny crystals will act as ready nucleation sites in the melt and lead to the refinement of the structure of the ingot.

The amount of pressure build-up in the melt is dependent on the agitating power of the gas bubbles in the bulk liquid and this is in turn a function of the amount of naphthalene addition. This study shows that more refinement of the ingot structure can be achieved with increasing naphthalene fraction. The melting point of the bulk liquid increases as the pressure build-up increases and hence the melt superheat decreases. So, refinement of the structure with naphthalene addition is analogous to the attainment of fine grain structure from low melts superheat. This has been verified by pouring a low melt superheat (40 C˚) of commercial aluminum, as shown in figure (4), where a completely refined grain structure has been attained.

Figure (5) shows the amount of compressed height under a fixed load of 150 KN as a function of naphthalene addition. It is clear that in both aluminum and zinc ingots, the compressed height increases with increasing naphthalene addition; i.e. the workability of the ingot improves. This is due to the contribution of the equiaxed grains in the structure with increasing naphthalene addition.

Naphthalene is a harmless compound [14] and can be applied safely under standard foundry conditions. There appear no barrier to its application in a wide range of non-ferrous casting processes. It is also soluble in some volatile liquids, such as alcohol, ether, acetone, and thus it can be successfully applied to the whole mould surface in the form of a thin layer, producing a multi-dimensional effect on subsequent casting. During solidification, gas bubbles evolution from sublimation of naphthalene is also expected to aid purification of the melt impurities or undesirable constituents. Furthermore, upon completion of solidification naphthalene leaves no harmful residue behind.

Conclusions

The following conclusions can be drawn from this study on grain refinement of a commercially pure aluminum and zinc castings by the addition of naphthalene:

1. The structure is more refined and the percentage volume of equiaxed grains increases with increasing amount of naphthalene addition.
2. The size of the shrinkage cavity in the cast structure decreases as the amount of naphthalene addition increases.
3. The ability of castings for mechanical working increases with increasing amount of naphthalene addition.

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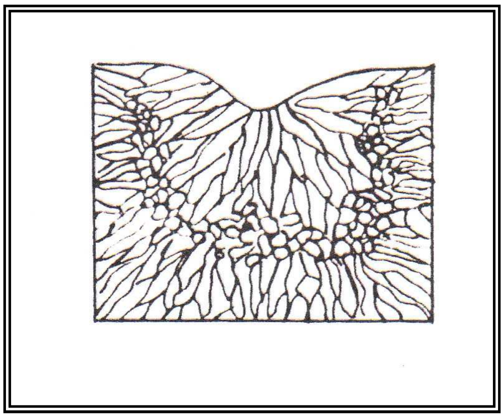
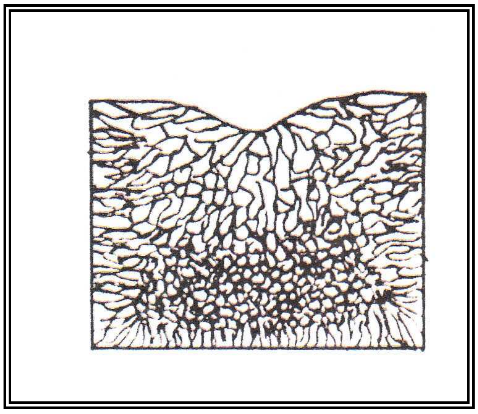
Table (1) Chemical composition (weight %) of commercially pure Aluminum and Zinc.

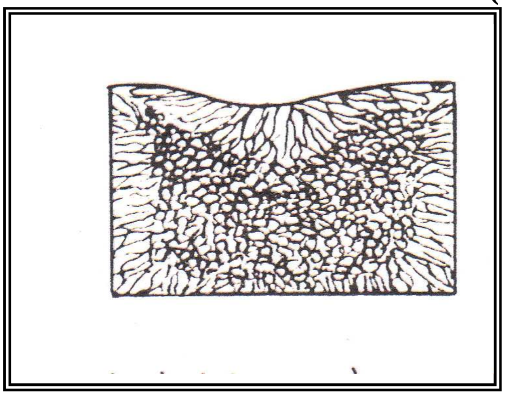
Commercially Pure Aluminum							
Si	Fe	Cu	Mn	Mg	Zn	Ti	Al
0.1	0.4	0.05	0.05	0.05	0.07	0.05	Balance

Commercially Pure Zinc				
Al	Pb	Cu	Fe	Zn
0.45	0.03	0.04	0.22	Balance



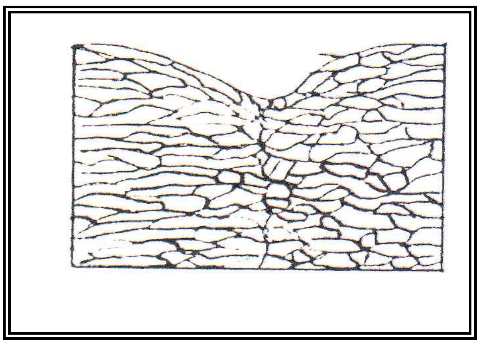


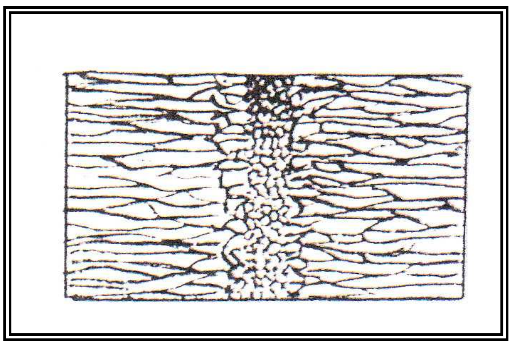
(a) 0 % naphthalene **(b) 1 % naphthalene**



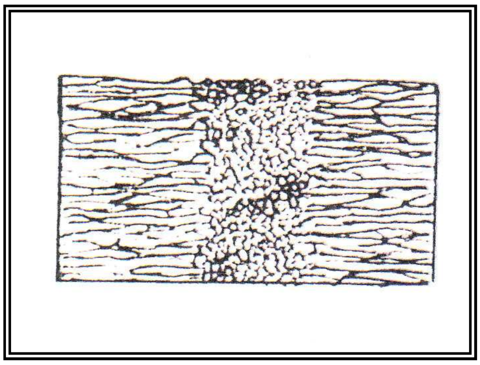
(c) 2 % naphthalene

Figure (1) Ingot structure of commercially pure aluminum with different naphthalene additions.

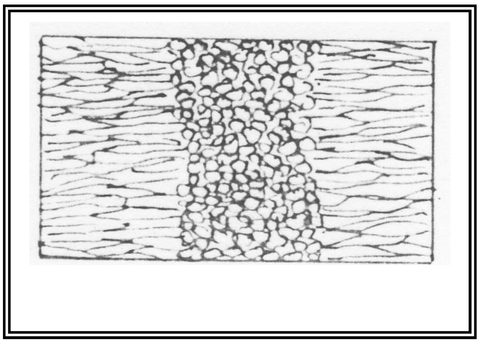




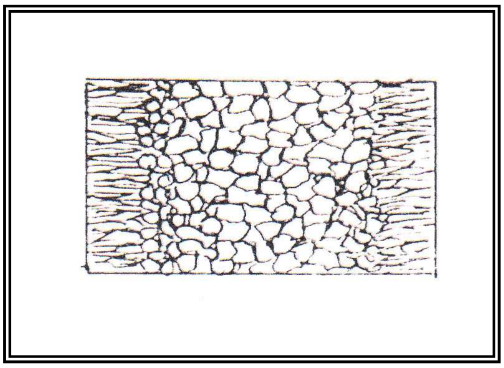
(a) 0 % naphthalene **(b) 1 % naphthalene**



(c) 3 % naphthalene



(d) 6 % naphthalene



(e) 9% naphthalene

Figure (2) Ingot structure of commercially pure Zinc with different naphthalene additions.

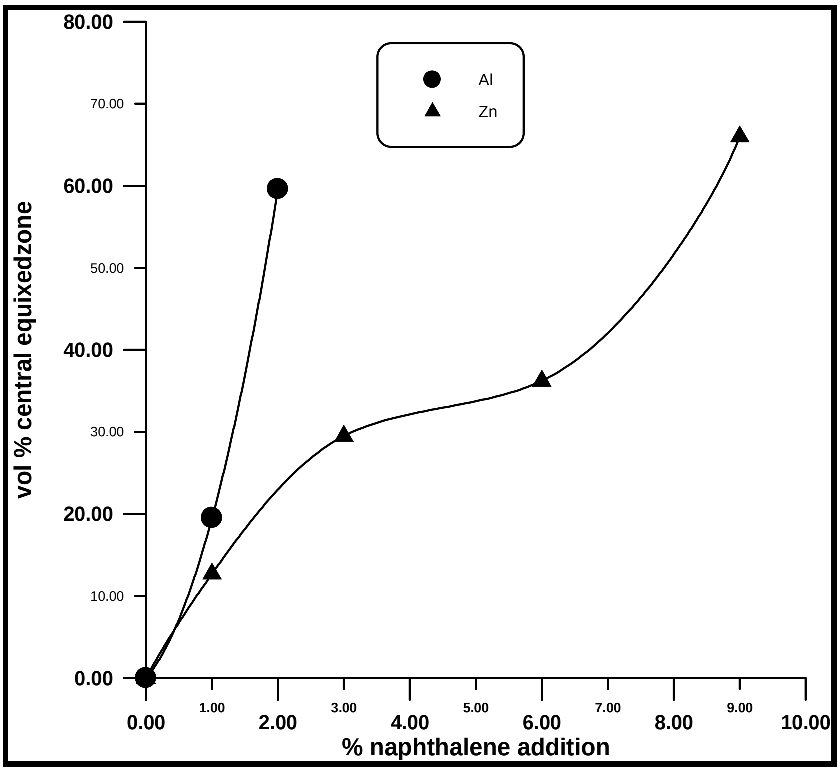


Figure (3) Effect of naphthalene addition on the % volume of equiaxed grains in the structure

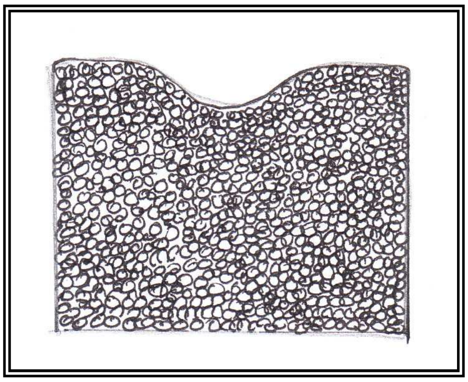


Figure (4) Ingot structure of commercially pure aluminum cast from (40˚C) super heat.

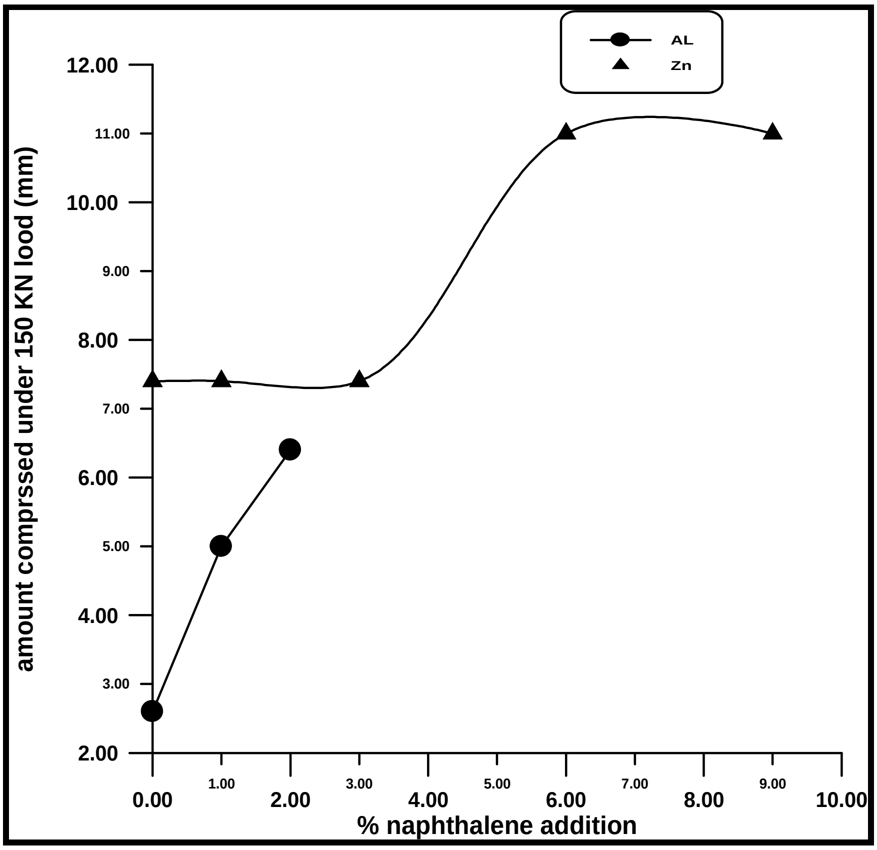


Figure (5) Compressed height under 150 KN loads as a function of naphthalene addition.