Investigation of nickel aluminium bronze castings properties by degassing agent technique

To cite this article: Kavinjr *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **469** 012037

IOP Conf. Series: Materials Science and Engineering 469 (2019) 012037 doi:10.1088/1757-899X/469/1/012037

Investigation of nickel aluminium bronze castings properties by degassing agent technique

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Abstract. Nickel Aluminium Bronze (NAB) is an excellent engineering material for maritime application due to its selective mechanical properties and relatively excellent corrosion resistant. However, NAB is susceptible to porosities due to dissolved gasses absorbed during its casting processes and adversely affects the mechanical properties. So, a degassing agent is added to the melt of NAB before the pouring process to reduce the dissolved gasses. A few parameters were initiated to investigate the effect of the degassing agent. Firstly, the effect of the degassing agent on the solidification behavior of the NAB alloy is studied using thermal analysis. Cooling curves can provide information on liquidus, eutectic, undercooling, recalescence and solidus temperature of the NAB alloy. Secondly, Differential thermal analysis (DTA) technique is employed to determine this thermal arrest temperature of NAB alloy from the cooling curves. The increasing in degassing agent addition will increase the average cooling rate of the NAB during solidification process but also slightly increasing the recalescence effect at the same time. It is discovered the higher cooling rate will reduce the dendritic growth and lead to better mechanical properties. Higher degassing addition also produced a smaller dendritic structure which promotes the higher mechanical strength. It has been proven through the tensile test, hardness test and microstructure analysis using FESEM. The relationship between, DAS average length, SDAS average length, tensile stress and hardness have been studied.

1. Introduction

Aluminium bronze was first discovered John Percy, an English metallurgist who found that a small addition of aluminium to copper can increase its hardness without affecting its malleability in 1856 [1]. Later, the nickel and iron are also added to the aluminium bronze to further improve its properties and then the NAB was born. The NAB is well known for its excellent mechanical properties and good corrosion resistant [2]. It is a type of copper alloys that has minimum 74.5% copper and containing 8.5-11.5% aluminium, 3-5% iron and 3-6% nickel as the major alloying metals. Other alloying metals such as manganese, silicon and lead also can be added to the alloy. Each of the alloying metals has their effect on the alloy. The addition of aluminium as well as iron and nickel can increase the strength of the NAB alloy. Nickel improves corrosion resistance, while iron acts as a grain refiner and increases tensile strength [3]. However, it is not recommended for the content of iron exceeds the nickel. According to their research, Nickel and manganese are also used as microstructures stabilizer. In short, the alloying metals are added to increase the mechanical properties and corrosion resistance of the NAB alloy [4]. Copper is one of the metal that possesses of high corrosion resistant but pure copper alone does not fit to the requirements of mooring components. This is because copper does not have the mechanical properties for maritime servicing. Therefore, copper must be alloyed with other alloying elements to improve its mechanical properties. Among the copper based alloys, the aluminium bronzes are known for its high mechanical strength, excellent corrosion and wear resistance [5,6]. Nickel Aluminium Bronze (NAB) is one of the aluminium bronze that has been widely used to manufacture maritime servicing components such as propellers and valves. NAB is one of the copper based alloys with addition of aluminium, nickel, iron and manganese as the alloying elements. This engineering material is widely used in maritime service because aluminium bronzes possess of exceptional corrosion resistance in seawater compared to other alloys.

However, the NAB is very difficult to cast due to the existing of casting defects such as shrinkage and porosity. According to Banchhor and Ganguly, risers design, gating system and moulding sand can affect the quality of the casting [7]. The risers are used to overcome the shrinkage defects. Ravi and Talapatra also stated the production of quality casting depend of the gating system [8]. Saikaew and Wiengwiset has found the optimum proportion for the bentonite and water for the recycled moulding sand for improvement of iron castings [9]. Therefore, casting quality is depending on the proper design of the sand mould and the moulding sand. Besides, the molten copper and molten copper based alloys are susceptible to dissolve gasses which will lead to porosity. These defects will adversely affect the mechanical properties of the NAB alloy. The porosity of the NAB casting can be reduced when the oxygen content of the NAB alloys can be controlled as low as possible. Therefore, in order to produce a NAB casting, the design of the mould and the addition of degassing agent are the parameters to be taken care so that the casting defects can be minimized. The introducing of degassing agent into the melt casting can reduce the dissolved oxygen in the melt casting and subsequently reduce the amount of porosity formed in the casting during solidification.

Therefore, the purpose of this project is to study the effect of the addition of degassing agent on the solidification of the NAB casting by using Thermal Analysis (TA). TA is an analysis of thermal signature due to the change in temperature during cooling or heating. This technique can predict the microstructure of the solidified alloy and hence the properties of the alloy. Degassing agent will be added to the molten NAB and TA will be implemented on the solidification of the NAB sample melt to predict the structure of Dendritic Arm Spacing (DAS) and Secondary Dendritic Arm Spacing (SDAS). This is important because the mechanical properties of the NAB casting are determined by the DAS and SDAS. Therefore, the DAS and SDAS which are influence by the time of the solidification can be determined using the TA.

2. Method

The raw materials to cast NAB alloy are copper, aluminium, nickel, iron and magnesium. The pure copper and aluminium are come in ingot form while others are readily to feed into the crucible. Thus, these two materials need to be cut into smaller pieces before they can be feed into the crucible. Band saw used to cut the materials into small cube.

After the cutting process, each alloying elements of the NAB alloys was weighted according the chemical composition of ASTM95800 specification as shown in Table 1.

Table 1. Chemical composition of NAB equivalent to ASTM B148 - C95800

Element	Composition (wt. %)
Copper	79.0 min
Aluminium	8.5-9.5
Nickel	4.0-5.0
Iron	3.5-4.5
Manganese	0.8-1.5

These materials were weighted by using weight scale equipment after calibrated according to the selected chemical composition indicated in Table I (approximately 1.5 kg). The observation on the melt was carried out regularly to ensure the materials must be fully melted before tapping temperature was achieved.

Green sand mixing was prepared to fabricate the mould which may replicate the pattern. The greensand is preparing by mixing the moulding sand, bentonite and water. Bentonite and water acts as the binder to hold the moulding sand. The mixing composition used in this research is 90% of moulding sand, 5% of bentonite and 5% of water. Shahria had founded that this is the optimum composition for casting and can produce the least number of defects [10]. The moulding sand is sieve before the mixing process so that finer grain can be compacted more easily and thus higher sand strength. Besides, this also can remove the contaminant in the sand which may affect the strength of the sand during compacting it. After mixing well the three ingredients, the greensand is ready to be used to make the mould.

The type of sand mould used in this research is a closed mould. Closed mould used in the present study has one sprue and two risers. The sprue is 100mm in length with diameter of 45mm at the top and 35mm at the bottom. The specimen on the other hand is cylindrical shaped having dimension of 240mm in length with diameter of 25mm. The gating system is fabricated in the way to let the melt filling the cavity from side. This is done by using a little bit of the greensand to block the gate of the upper part of the mould. The mould cavity is consisting of one specimen, sprue and two risers is shown in Figure 1.

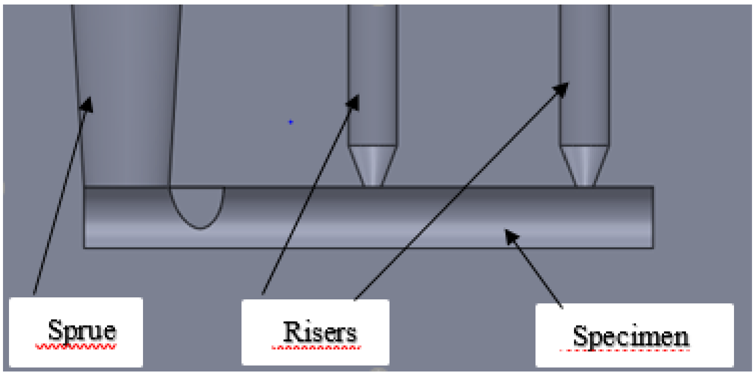

Figure 1. Gating system of mould.

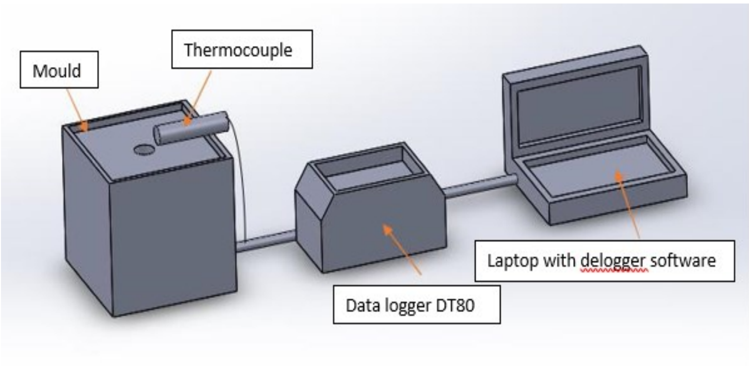

Figure 2. Schematic arrangement of thermal analysis set up for solidification monitoring.

Figure 3. The mould is fabricated in bottom filling system.

Before the melting process, the graphite crucible needs to be coated with zircon flour, sodium silicate and colloidal silica. This is because the graphite crucible will deteriorate when the vessel is heated. In order to extend the lifespan of the crucible, zircon flour and the colloidal silica with the sodium silicate can be coated on the outer wall of the crucible. Besides, it also provides good insulating to the casting by reducing the heat dissipated to the surrounding. The coating process is done by apply the colloidal silica mixed with sodium silicate as the binder at the outer wall of the crucible and then spread the zircon flour evenly on the crucible. The coating is allowed to dry first before another layer is layer is applied. This process is repeated four times to produce four layer of coating on the crucible.

Figure 4. Graphite crucible coated with zircon flour bind using sodium silicate and colloidal silica.

Melting process started with a charging of raw materials into the crucible. When loading the raw melting into the crucible, it must be done slowly and carefully. Dropping the raw materials directly into the crucible can caused physical damage to the crucible and subsequently failure can happen. Due to the size of the crucible, not all materials can be fed into the crucible at once. Therefore, copper is first melting using the induction furnace and followed by adding alloying metals. The alloying metals are added in sequence of nickel, iron, aluminium and lastly manganese. The induction furnace is operated at 1000Hz for 30 seconds and then switch off for 10 seconds and repeating the cycles. The melt is then superheated to 1150±50°C.

Figure 5. Induction heating by induction furnace.

Degassing agents need to be added just before the pouring process. Due to the density of the degassing agent is generally lower than the molten metal, the degassing agents will not sink into the melt but float on it. Therefore, it is necessary to push the degassing agents into the melt. This is must be done in gently without disturb the melt too much. According to Campbell, stirring will caused the inclusions that settle in the bottom of melt re-introduce into the melt and subsequently wrecking the quality of casting [11]. An incubation time of 5 minutes is given after the addition of the degassing agent before the pouring process. The degassing agents used was 0.5%, 0.7%, 0.9%, and 1.1% of the total weight of the NAB. The degassing agent used in this project is calcium boride. Therefore, the deoxidation of oxygen content of the molten NAB alloy by mean of calcium boride is used in experiment. Calcium boride is a deoxidation agent which can be used to react with the dissolved oxygen inside the melt and subsequently reduced the oxygen content in the casting. During melting, the slag and impurities will float on the top of the molten alloy. This dross must be skimmed off before the pouring process. This is because they can lead to clog up at the sprue. After the oxide layer is being skimmed off, the molten NAB casting is poured into the mould. The casting will be left to be solidified inside the mould for certain period. After that, the mould will be break to obtain the casting inside the mould.

The TA is conducted on the 110±10g of NAB melt sample by recording its temperature history during solidification. The molten melt sample is cooled from 1150±50°C until 900°C. The cooling curve of the NAB melt sample is obtained by using a single Type R thermocouple. The thermocouple is implanted in the permanent mould and the real time temperature reading of the casting was registered as it cools. The permanent mould used in present study is made by the isolite brick. The electrical output of the thermocouple is measured and converted into the temperature readings by the high speed data acquisition data logger. The data logger used in the present study is Graphtec Midi Logger GL220 and is shown in Figure 6.

Figure 6. Graphtec Midi Logger GL220 used for recording the temperature data.

Figure 7. Casting of NAB alloy after solidification.

Those readings registered by the data logger will be uploaded to personal computer (PC) with GL-Connection software installed which the data logger linked to. The sampling rate of the temperature measurement is set to 1/10 second so that the signal is recorded each 0.1s throughout the solidification process for all the experiments. This is to increase the accuracy of the data taking and minimize the loss of data. The temperature measurement is started as soon as the pouring of molten metal into the mould. The recorded temperature readings are then transferred to the Microsoft Excel for plotting the cooling curves of each solidification. The first order derivative of the cooling curve which is the instantaneous cooling rate is used for analysing the solidification behaviour. This first derivative curve is derived from the cooling curves and will be used to interpret and determine the phase transition temperature such as TAL, TES, TEU, TER and TEE.

The cylindrical shaped NAB alloys were machined by using conventional lathe machine as shown in figure 8. The bone-shaped specimen was produced which will mount in the tensile test machine to break the sample in order to be used for microstructural examination on fracture surface in the next process.

Figure 8. Turning process of NAB alloy using lathe machine.

Tensile test is used to evaluate the strength of the NAB specimens. In this test, the specimens were pulled to failure in a relatively short time at a constant rate. The ability of a material to resist breaking under tensile stress is one of the most important and widely measured properties of materials used in structural applications.

Figure 9. Specimen after tensile test

Figure 10. Specimen that used for microstructural examination in SEM

Figure 11. Specimen that used for microstructural examination in Optical Microscopy and XRD

After the specimen was cut, only the specimen that used for microstructural examination in optical microscopy needed to undergo the hot mounting, grinding, polishing and etching process. The hot mounting process is used to produce uniform size specimen and easier to be handled during grinding, polishing and etching process. The specimen was placed inside the hot mounting machine with mounting resin and mounted under pressure in a mounting press during the hot mounting process.

Figure 12. Samples after hot mounting process

Surface layers damaged by cutting must be removed by grinding. Mounted specimens was ground with abrasive paper. The coarseness of the paper is indicated by a number. The grinding procedure involves several stages, using a finer paper (higher number) each time. For the beginning of the grinding process. The 240 grit of abrasive paper was used and then continued to 320, 400 and 600 grit accordingly. Each grinding stage removes the scratches from the previous coarser paper. This can be easily achieved by orienting the specimen perpendicular to the previous scratches. During grinding process, water as a lubrication was supplied to the abrasive paper surface.

There are two stage which are coarser polish and finer polish. For a coarser polish, the polishing discs was covered with red felt cloth impregnated with 1-micron diamond compound particles and microid extender. For a finer polish was covered with wetted imperial cloth impregnated with colloidal silica. The specimen was polished to remove the scratches produced from the finest grinding stage in coarser polish and a finer polish was used to produce a smooth surface. A complete polished specimen was cleaned by running water and dried by using cotton bud.

Etching is used to reveal the microstructure of the metal through selective chemical attack. In alloys with more than one phase etching creates contrast between different regions through differences in topography or the reflectivity of the different phases. In this process, nitric acid was used as an etchant. First of all, the sample was cleaned by using distilled water and wiped by a cotton bud. Next, it was immersed in the etchant for a few seconds. After that, it was washed again with distilled water and dry with the fan.

In order to evaluate effect of degassing agent addition on the microstructure of cast nickel aluminium bronze (NAB). The optical microscopy was used. The optical microscopy will display two-dimensional of microstructure image with 50x of magnification. In SEM inspection, the fracture specimen was used to evaluate the effect on microstructure of cast nickel aluminium bronze (NAB) with different degassing agent addition. The EDS is a chemical microanalysis technique used in conjunction with scanning electron microscopy. The EDS was used to reveal the elemental composition. XRD analysis is used to identify element phases. For the XRD analysis, the scanning range was 5 degree to 180 degree.

3. Results and discussion

The cooling curve presents the solidification stage of the NAB from the pouring process until it fully solidified inside the mould. The solidification behaviour of the casting can be obtained from the cooling curve. The cooling curve thermal analysis for the solidification of NAB alloy is performed with different amount of degassing agent addition which are 0.5%, 0.7%, 0.9% and 1.1% of the overall weight of the melt. Figure 13 depicts the cooling curve of the NAB with 0.5% of degassing agent addition recorded using the thermal analysis equipment after calibrated.

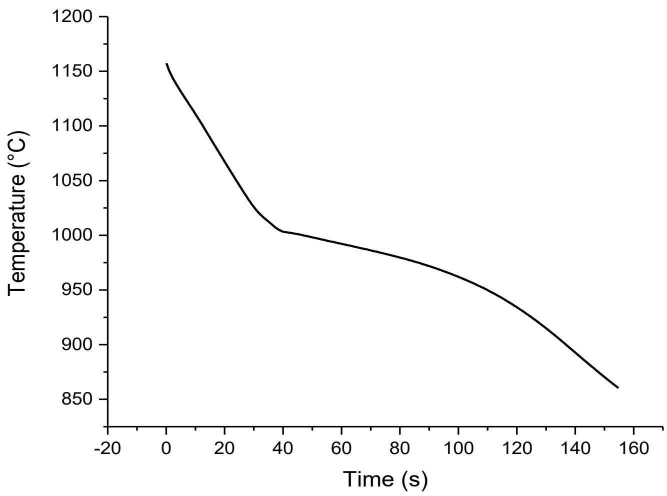

Figure 13. Cooling curve of NAB with 0.5% of degassing agent addition

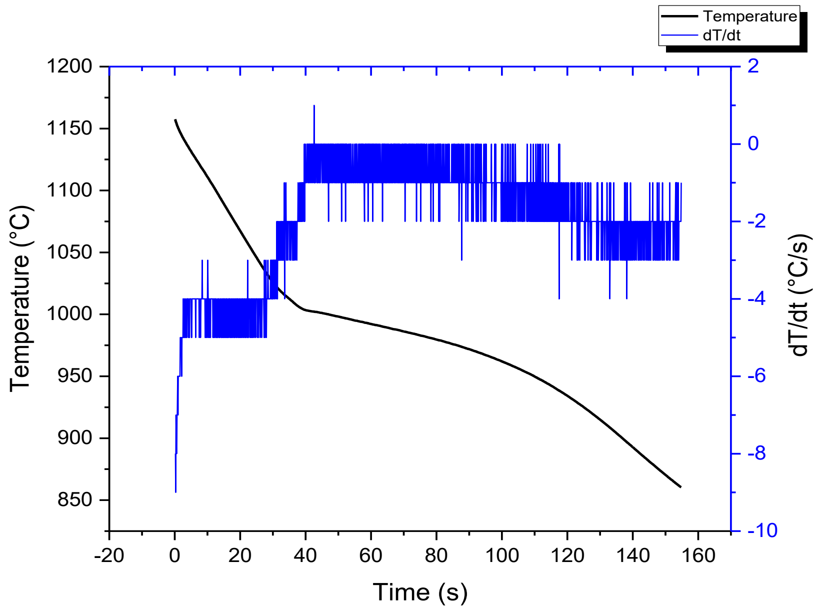

Figure 14. Cooling curve of NAB with 0.5% of degassing agent addition and its first derivative curve.

The cooling curve of the NAB with 0.5% of degassing agent addition and its first derivative (Blue curve) are presented in figure 14. The purpose of the constructing the derivative of the cooling curve is to identify the five thermal arrests from the cooling curves which are TAL, TES, TEU, TER and TEE. Thermal arrest is the cooling curve formed when a material is solidified due to latent heat of fusion. These thermal arrests in the cooling curve due to the solidification of NAB alloy will give the information on how the physical properties of the NAB will be.

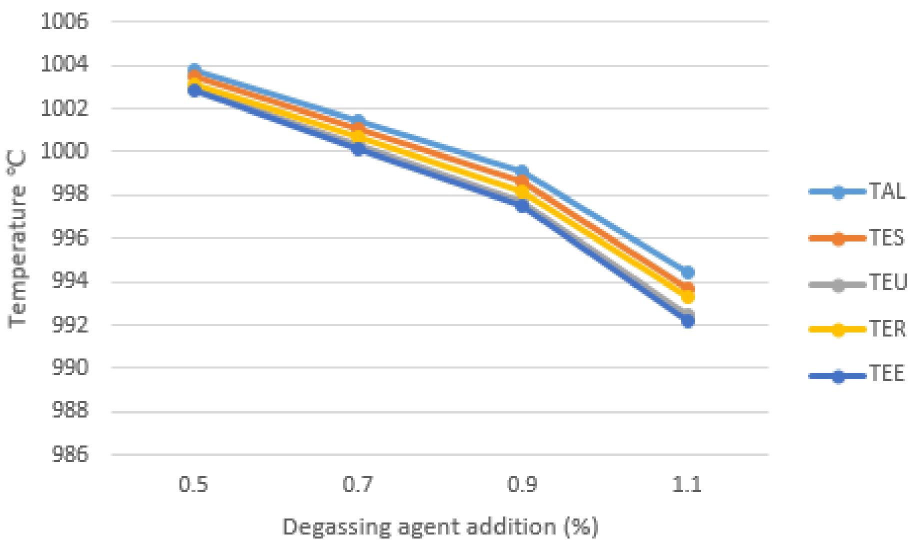

Figure 15. Effect of degassing content on TAL, TES, TEU, TER and TEE

TAL, TES, TEU, TER and TEE are decrease with the increase of degassing agent addition as shown in Table 4.1. These thermal arrest points are highest when the addition of degassing agent is 0.5% and gradually decreasing as the addition of degassing agents increased from 0.5% to 1.1%. This results indicates that the increasing cooling rate of the NAB alloy causes a decreases in the values of the thermal arrest points.

From the tensile test, the mechanical properties of the specimen such as ultimate tensile stress, maximum elongation strain and elastic modulus can be determined. There are four specimens range tested using the same cross section and load speed. The specimens were prepared per ASTM B148 standards for tensile test.

Table 2. Values of tensile stress, macro hardness and micro hardness for each amount of degassing content.

Degassing content (%)	Tensile stress (MPa)	Macro hardness (HRB)	Micro hardness (HV)
0.5	161.09	90.36	228.00
0.7	180.02	90.55	242.67
0.9	185.69	91.22	260.17
1.1	228.76	93.33	265.20

1.1% of degassing content in the specimen has the highest value of tensile stress which is 228.76 MPa compared to 0.5% of degassing content specimen which has the lowest value of tensile stress which is 161.09 MPa. When the degassing content increases, the tensile stress increases. The value of the macro hardness increases when the higher amount of degassing content is used. For 0.5% of degassing content, the lowest macro hardness value is 90.36 HRB. Meanwhile the highest value of the macro hardness is 93.33 HRB when the 1.1% of the degassing agent is used. Micro hardness also increases when using the higher amount of degassing content. For 0.5% of degassing content used, the value of the micro hardness is 228 HV which is the lowest. The value of the micro hardness also increases until 265.2 HV by addition of 1.1% degassing agent.

4. Conclusion

There is significant relationship of degassing agent effect towards alloy solidification. Degassing agent minimize the dissolves gas by accelerate the solidification time stages. Tensile and micro hardness affected directly by the changes of the solidification stages. Both values increase as well amounting of 42% (tensile stress) and 16% (micro hardness) of lesser degassing added. It is proposing the tensile and micro hardness affected due to changes of alloy's microstructure during solidification stages. The solidification phase influenced the nucleation and growth phase range and time. However, it is required a specific solidification study in the near future to conclude the finding. There is no significant effect on macro hardness (3%) of the alloy because macro hardness is affected probably by the mechanism of macro segregation of elements, which required further investigation.

Acknowledgment

The author expresses his sincere thanks for the financial support of the Ministry of Education (Malaysia) under contract no. RDU 160378.

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