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The effects of Heat Treatment (T6) Technique and Some Centrifugal Casting Parameters on the Fatigue behavior of the Composite Material (A380/Al₂O₃)

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Abstract

Aluminum alloys composite is one of the most common types of composite materials and are used a lot in the recent years. In this paper, it had been dealt with the effects of the heat treatment techniques and some centrifugal casting parameters on the fatigue behavior of the composite material (A380/Al₂O₃) for high-cycle fatigue resistance which is one of the most important property for the automotive industry. It has been used aluminum alloy A380 with alumina particles Al₂O₃ to form composite materials through the process of centrifugal casting. The proportions were 10% and 20% with a grain size 63μm. After there, it has been manufactured Thirty-two models of composite material (A380/ Al₂O₃). Half of them are examined directly without treatment while the other half was treated with (T6) and then examined. The results showed that adding the amount of alumina 20% without heat treatment will increase relatively resistant composite material for the fatigue resistance by 17% percentage. And adding 10% alumina to the composite material and them cause distortion of the surface structure samples had been by blisters with completely discolored. A high Alumina content improves the fatigue behavior of the composite material (A380/Al₂O₃).

Keywords: Fatigue test, heat treatment, centrifugal casting, aluminum alloy, composite material.

تأثيرات تقنية المعاملة الحرارية (T6) وبعض العوامل المتغيرة لسبائك الطرد المركزي على تصرف خاصة الكلال للمادة المركبة (A380/Al₂O₃)

الخلاصة

سبائك الألمنيوم المركبة هي واحدة من أهم الأنواع الشائعة للمواد المركبة والمستخدمة كثيرا في السنوات الأخيرة. في هذا البحث تمت دراسة تأثيرات تقنية المعاملة الحرارية (T6) وبعض العوامل المتغيرة لسبائك الطرد المركزي على تصرف خاصة الكلال للمادة المركبة (A380/Al₂O₃) وذلك لان خاصية الكلال واحدة من أهم الخواص التي تدخل في صناعة السيارات. استخدمت سبيكة الألمنيوم A380 مع جسيمات الالومينا Al₂O₃ وبالنسب (10% و 20%) ذات الحجم الحبيبي (63μm) وذلك لتكوين المادة المركبة عن طريق عملية السبائك بالطرد المركزي. على كل حال، تم تصنيع اثنان وثلاثون عينة من المادة المركبة (A380/Al₂O₃) أعلاه، حيث أن نصف النماذج اجري عليهم فحص الكلال مباشرة والنصف الآخر أجريت له المعاملة الحرارية (T6) وبعد ذلك اجري لهم فحص الكلال أظهرت النتائج إن إضافة كمية من الالومينا بنسبة 20% إلى سبيكة الألمنيوم A380 وبدون إجراء المعاملة الحرارية سوف تزداد نسبيا مقاومة المادة المركبة للكلال بنسبة 17% وعند إضافة 10% من الالومينا إلى سبيكة الألمنيوم وبعد إجراء المعاملة الحرارية تم ملاحظة

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وجود مسامات صغيرة بصاحبها تغير اللون السطح الخارجي للعينات عند فحصها مختبريا. وأخيرا، تم استخدام كمية كبيرة نسبيا من الالومينا وذلك لزيادة مقاومة المادة المركبة للكلال.

الكلمات الدالة: فحص الكلال، المعاملة الحرارية، سباكة الطرد المركزي، سبيكة الالمنيوم، المادة المركبة.

Introduction

Aluminum matrix composite is one of the most conventional types of metal matrix composites [1]. Among various functionally gradient materials (FGMs), metal-ceramic FGMs, also called metal matrix composite FGMs are of great practical interest. These FGMs feature gradual compositional variations from metal concentrated region at one surface to ceramic concentrated region at the other, leading to control gradation of physical, mechanical and / or chemical properties across the thickness accompanied by minimizing stress concentration at the interface of dissimilar materials. Therefore, such FGMs are rapidly finding applications in aggressive environments with steep temperature gradients such as rocket nozzle, thermal barrier coatings, turbine components, jet engine etc., and in some typical automobile components [2].

METAL-MATRIX COMPOSITES (MMCs) have been used commercially in the automotive market for nearly 20 years. Properties of interest to the automotive engineer include increased specific stiffness, wear resistance, and improved high-cycle fatigue resistance [3]. Today there is no doubt that the automotive industry is the most important consumer of aluminum alloy shape castings. Each year the overall volume of cast aluminum in automotive technologies grows steadily. This is especially true during the last 10 years, when the production of "aluminum" cars started and the number of aluminum-intensive vehicles grew rapidly. Such details as cylinder blocks, pistons, other engine parts, frames, and covers of different devices "under the hood" are traditionally cast from aluminum now. All these complex details and products are manufactured using different casting techniques and amount to many millions of parts per year. Due to their excellent specific strength, corrosion resistance, and relatively low labor intensity of production, cast aluminum alloys are also widely used in other transportation sectors of the economy such as aerospace, marine, and railroad transportation [4].

Some 238 Compositions for foundry aluminum alloys have been registered with the Aluminum Association. Although only

46% of this total consists of aluminum-silicon alloys, this class provides nearly 90% of all the shaped castings manufactured. The reason for the wide acceptance of the 3xx.x alloys can be found in the attractive combination of physical properties and generally excellent castability. Mechanical properties, corrosion resistance, machinability, hot tearing resistance, fluidity, and weldability are considered the most important [5]. Addition of ceramic particles to aluminum matrix would improve the strength, hardness, wear resistance and corrosion resistance of the matrix [6]. Al_2O_3 is the most popular among ceramic particle reinforcement after SiC particles. Al_2O_3 has higher thermal stability compared with SiC, since it does not react with the metal matrix at high temperatures and does not produce brittle phases [7].

Centrifugal casting is one of the cast technology usually associated with obtaining of functionally graded materials mainly composite materials metallic materials which have high difference of density and low solubility on different phases or different materials of the same alloy [8]. Centrifugal casting has emerged as simplest and cost effective technique for producing large size engineering components of functionally graded metal matrix composites [9]. Furthermore, low-cast, high-volume production methods are available now, including powder metallurgy, stir casting, pressure or pressure less infiltration, spray deposition, etc. [10].

The understanding of the correlation between microstructure, deformation, damage initiation and damage development in composite materials is of major importance for engineering materials and their commercial use in automotive and aerospace systems. The degree of property improvement depends on morphology factors such as volume fraction, size, shape and spatial distribute of the reinforcements, in addition to the constituent material and interfacial properties [11].

Most of the heat-treatable aluminum alloy systems exhibit multistage precipitation and undergo accompanying strength changes analogous to those of the aluminum-

copper system. Multiple alloying additions of both major solute elements and supplementary elements employed in commercial alloys are strictly functional and serve with different heat treatments to provide the many different combinations of properties--physical, mechanical, and electrochemical--that are required for different applications. Some alloys, particularly those for foundry production of castings, contain amounts of silicon far in excess of the amount that is soluble or needed for strengthening alone. The function here is chiefly to improve casting soundness and freedom from cracking, but the excess silicon also serves to increase wear resistance, as do other micro-structural constituents formed by manganese, nickel, and iron. Parts made of such alloys are commonly used in gasoline and diesel engines (pistons, cylinder blocks, and so forth).[12].

Zho et al. [10] showed the high content of Al_2O_3 particulates and the high thermal and elastic incompatibilities between the Al matrix and Al_2O_3 particulates result in brittle fracture and low fracture toughness for the composite. Zhang et al. [13] prepared single kind of in situ Mg2Si particles to reinforce Al based functionally gradient composites using centrifugal casting process. Sopha et al. [11] suggested damage criteria in order to foresee the degradation process in an Al_2O_3 -particle reinforced Al(6061) composite during mechanical loading. Rajan and Pai [9] discussed the formation of solidification microstructures in centrifugal cast functionally graded aluminum composites, and they are found that the densities and size of the reinforcements play a major role in the formation of graded microstructures. Balout and Litwin [14] developed by mathematical modeling of particle segregation during centrifugal casting of metal matrix composites that the particles volume fraction on the outer casting face varied according to whether the viscosity of the liquid metal used was constant or variable. Rahmani et al. [1] deals with the effect of production parameters on wear resistance of Al_2O_3 composites and it was found that increasing sintering temperature results in increasing density, hardness and wear resistance and homogenization of the microstructure. Li et al. [15] analysed the residual stress distribution near the interfaces in a SiC/6061 Al composite depending on different low temperature treatments and showed the

effective methods of reducing such stresses. Chirita et al. [16] discussed the mechanical properties advantages of using the vertical centrifugal casting technique for the production of structural components when compared to tradition gravity casting. Burton et al. [17] used the fatigue test of A380 aluminum alloy specimens machined from the cast, and micro structurally-based fatigue model to estimate the fatigue life of the pivot arm. This paper concludes with suggestions for increasing the fatigue life of the pivot arm.

According to this study, the research will be divided into three goals: the first will add an Al_2O_3 particle to A380 alloy through the centrifugal casting technique, the second is an examination of fatigue property on the composite material, and finally perform the heat treatment of the composite material with the study of their effect on the fatigue property.

The Experimental Work

Materials and Experimental Procedures

In this investigation, the composite material Al380/ Al_2O_3 consists of two phases: metal matrix Al380 and (10&20) vol.% of Al_2O_3 ceramic particle distributed in the matrix. This material has been fabricated via metallurgical route when The material was melted at 750 °C in the electrical furnace and poured into the permanent die which was preheated at 450 °C. After that Al380/ Al_2O_3 extruded to required specimens and heat treated in a defined way to achieve fatigue behavior.

It was used particles of alumina as a strengthening of purity 99.9% of the production company (Panreac) and molecular weight (Molecular weight) 101.96, as controlling was the grain size of the particles by a group of sieve vibratory ranging size 63microns. Metal base cleaned, which is a cover cylinder internal combustion engine of Toyota car type CZK Model (1980-1981), Where the grease is removed from it and cutting into pieces weighing one part of which 2 kg with the removal of all the accessories that differ in their chemical composition metal required for the foundation and It was subsequently create a melting furnace. The control of the melting temperature is up by a digital control system for temperature molding required. Note that he was conducting chemical analysis of alloy (spectral analysis) in Al Nasr General

Company, Table (1) the chemical composition of the base alloy used in this study. In order to determine the appropriate conditions for the production of composite

material consisting of the base alloy (A380) and alumina particles, it was the study of the following variables:

Table 1: Experimental chemical composition of Al380 alloy, (%wt).

Elements	Al	Si	Cu	Zn	Mg	Ni	Mn	Pb	Fe	Ti	Cr
%wt	86.95	8.11	3.35	0.18	0.31	0.019	0.14	0.020	0.55	0.014	0.0180

1- Pouring and Die temperature.

2- Rotational speed of the die.

Where we put metal parts in the crucible of ceramic from Carbide silicon and then put into the furnace with temperature control through the control system of digital and when we reach the temperature 750C° and then installed temperature furnace then we added 1% slag remover of German origin with type (KALF4) to molten metal aluminum alloy (A380) high-density 2.71g/cm³ where it is mixed with molten metal by ladle iron hand, we removal of the slag by ladle [18]. Then it has been added particles alumina -density (3.97 - 3.986) g/cm³ and imperceptibly to the center of the vortex and the proportions volumetric particles was amount 10% and 20%, where they were mixing particles with molten metal by mixer electrician (Electrical stirrer) and quickly rotate 500 r/min.

The initial process of mixing continues one minute and then the temperature raise of the furnace to pouring temperature required at this temperature is installed furnace temperature in order to be mixing process on the second stage and a time range between (1-2 minutes) and at the same rotational speed mixing primary and then the mixture be pour into mold machine centrifugal horizontal. After that we take the product and then our own making 32 sample to examine the fatigue behavior by the CNC machine as shown in Figs. (1) and (2).

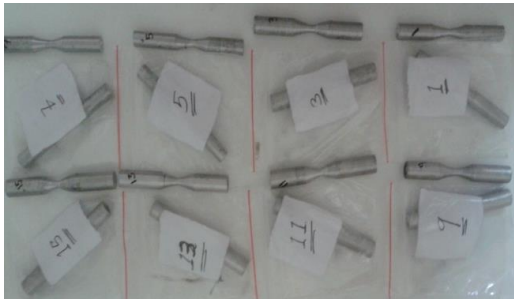


Fig. 1. Image models, which contain 10% Alumina

Testing Machine

The selected testing machine was made by (HI-TECH SCIENTIFIC), that is shown in Fig. (3). This machine was used for testing works by rotating fatigue and has a property of automatic cut-off as specimen fails.



Fig. 2. Image models, which contain 20% Alumina.

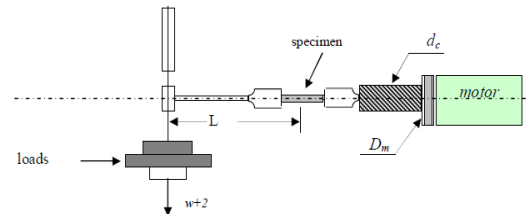


Fig. 3. Fatigue testing machine.

Applied Stress Calculation

From Fig. (3); Motor speed, $\omega_m=1425$ rpm. mean diameter of the motor pulley= $D_m=73$ mm. mean diameter of chuck pulley= $d_c=36.5$ mm.

$$(\omega)_{\text{chuck}} = (\omega)_{\text{motor}} \times \frac{D_m}{d_c} \quad (1)$$

Thus; $(\omega)_{\text{chuck}}=2850$ rpm=chuck speed. The testing machine applies a bending stress on the specimen, which can be determined as follows:

$$\sigma = \frac{Mr}{I} \quad (2)$$

Thus;

$$M = F \times L \quad (3)$$

$$F = \omega + 2.7 \quad (4)$$

$$r = \frac{d}{2} \quad (5)$$

$$I = \frac{\pi d^4}{64} \quad (6)$$

where w is the applied load in Newton and $L=139$ mm, F is the applied force in Newton, d is the diameter of the specimen and it is equal to 4 mm, then; $M = 139F$ (N.mm), $r = 2$ mm, and $I = 12.566 \text{ mm}^4$, thus;

$$\sigma = 25.465 \times F \quad (7)$$

The number 2.7 in Eq. (4) represents a combination of (2N, which is the weight of the loads holder) and (0.7N, which is the equilibrium weight). The stress (σ) in Eq. (7) represents the nominal applied stress, while a stress concentration must be calculated due to the reduction in cross-sectional area of the specimen as shown in Fig. (4)[19]. where L is the distance between center of notch and the center of load.

For Rotating fatigue machine type Hi-TECH: $L = 139$ mm.

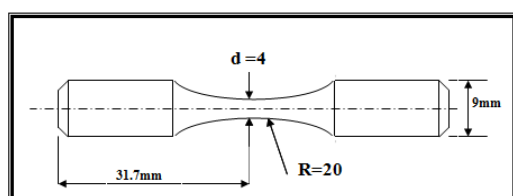


Fig. 4. The dimensions of fatigue test specimen.

Preliminary heat treatment experiments were performed using 32 specimens of composite alloy (A380/Al₂O₃), the chemical compositions of which are summarized in Table (1). Composite material was used to produce standard fatigue specimens Figs. (1) and (2). The fatigue specimen was subjected to solution treatment at different temperatures and visually examined for the occurrence of "blisters". Solution treatment was performed in an air-circulating furnace for 8 hours at temperatures ranging from 505 °C and the samples were quenched in the natural aging,

then aged for 3 hours at 155°C and their room temperature fatigue properties was measured.

This preliminary study shows that Composite can be subjected to a T6 heat treatment without causing any surface blistering. This is achieved by solution treating the specimens for much shorter times and at lower temperatures than those used for heat treating specimens that were cast in permanent molds.

Heat treatment comprises all thermal practices intended to modify the metallurgical structure of products in such a way that physical and mechanical characteristics are controllably altered to meet specific engineering criteria. In all cases, one or more of the following objectives form the basis for temper selection:

- Increase hardness for improved machinability.
- Increase strength and/or produce the mechanical properties associated with a particular material condition.
- Stabilize mechanical and physical properties.
- Ensure dimensional stability as a function of time under service conditions.
- Relieve residual stresses induced by casting, quenching, machining, welding, or other operations[5].

Solutionizing at 505 °C for 8 hours ensures a blister-free sample and the fatigue properties are significantly improved. The specimens were heated to 505 °C, stabilized at this temperature for 8 hours, then the pieces are left in the furnace to cool and then heated to 155°C for (3) hours to obtain artificial aging as shown in Fig. (5) .

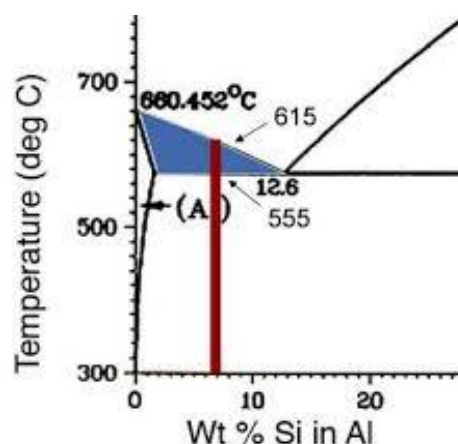


Fig. 5. Portion of Aluminum-Silicon binary phase diagram.

Results and Discussion

The effect of the amount of alumina on microstructure is shown in Figs. (6) and (7) which presents the effect of alumina particle size on the microstructure after solution heat treatment (T6) at 505 °C for 8h then we applied precipitation at 155 °C for 3hr . At high amount of the reinforcement, a finer grain was observed in the microstructure. It seems that alumina particles act as a barrier against the movement of grain boundaries and hence retards grain growth.

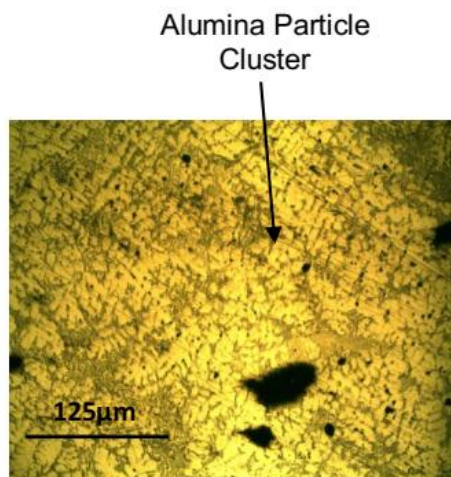


Fig. 6. The shape and size of clusters alumina particles with morphology phase eutectic when alumina ratio of 10%.

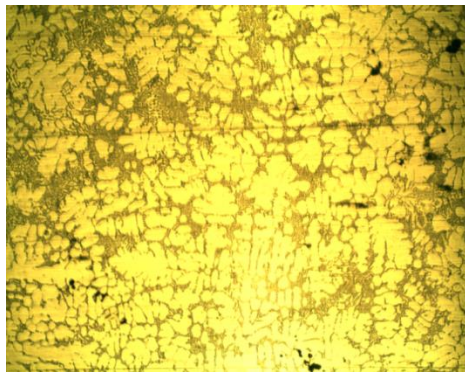


Fig. 7. The shape and size of clusters alumina particles with morphology phase eutectic when alumina ratio of 20%

To study the effect of heat treatment T6 on some samples, which were used to examine the fatigue behavior, where we used an electric furnace so as to reach this alloy composite (A380/Al₂O₃) to a temperature of 505. Figures (3a) and (3b) show the difference in the structure

of the outer surface of samples where on the one hand the blisters show clearly on the surface of some of the samples and that the fatigue behavior negatively effect, so the specimens became completely discolored and many blisters were observed on the surface as shown in Fig. (8)a. On the other hand, the remaining samples was not affected its surface of heat treatment with stay the fatigue property virtually unchanged as shown in Fig. (8)b.

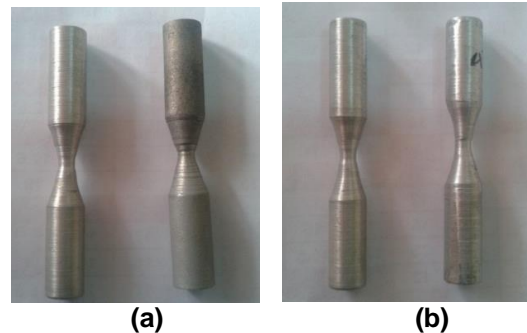


Fig. 8. (a) The existence of discolored and many blisters, and (b) Illustrates the non-existence of discolored and blisters.

This is due to the proportion of ceramic added to the alloy of aluminum (A380) as the increase this percentage to 20% may have helped to prevent the appearance of blisters in the structure of the outer surface of the samples, and in general it can be said that the 20% was better than the 10% when we used Solution heat treatment as show in curves at Figs. (9) and (10). We conclude from the above that the alumina particles have helped to increase the temperature range of solution heat treatment in addition to its ability to improve the strength, hardness, wear resistance, corrosion resistance and increasing the fatigue life of the matrix. It is clear by the results that the centrifugal technique substantially improves the mechanical and fatigue properties of the material.

Conclusions

The main conclusions of this work are:

- 1- Proper solution and precipitation temperature results in improved fatigue properties, however, excess heat treatment conditions deteriorate the fatigue properties to grain growth and reduced hardness.
- 2- Addition of alumina, considerably improves the fatigue properties of aluminum alloy A380 in all fatigue test distances. For

instance, addition of 20wt.% alumina improves the fatigue properties. For example, the fatigue rate decreases by 17% if alumina particle ratio reduces from 20 to 10wt%.

- 3- Elevates temperature to 505 °C help reduced relative porosity and enhance densification, whereas stay solution time to 8hrs leads to grain coarsening.
- 4- High amounts of alumina lead to reduced relative porosity and, large alumina size raises the relative density initially and drops it later.

5- Increasing the amount and reducing of alumina promote high hardness in the composite. Maximum hardness of 92HB was observed in the specimen containing 20wt% alumina.

- 6- The fatigue life can be improved by reducing the porosity in the casting.
- 7- Reducing the pore size and porosity level in the casting can be accomplished through alterations in the casting process.

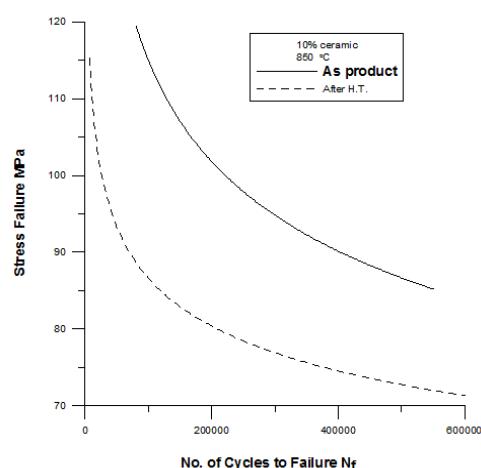
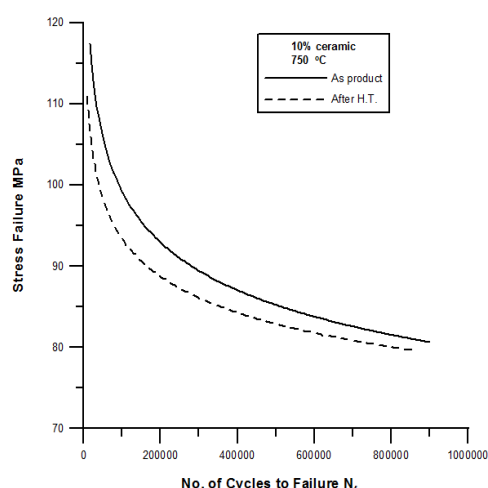


Fig. 9. Fatigue curve for the composite material A380/Al₂O₃ with 10% ceramic at 750 and 850°C.

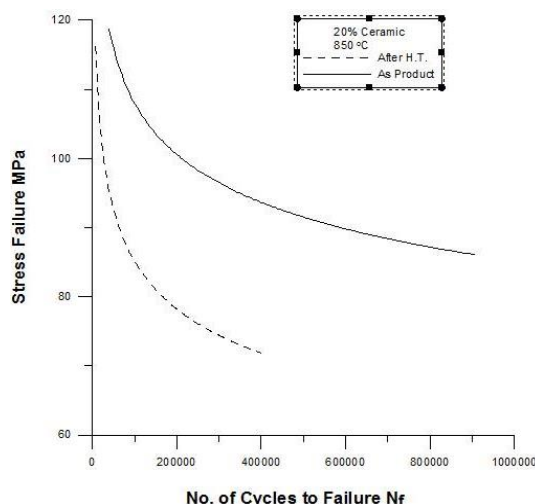
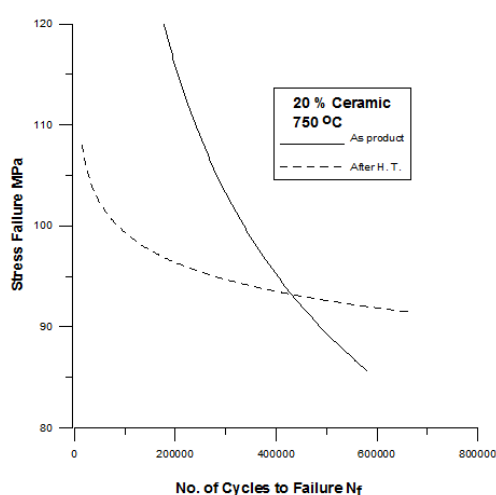


Fig. 10. Fatigue curve for the composite material A380/Al₂O₃ with 20% ceramic at 750 and 850 °C.

- 8- It is possible to obtain much better pore size and porosity level in fatigue specimens after heat treatment by using specimen was cast at 750 °C pouring temperature as compared to 850 °C pouring temperature.
- 9- When adding 10% alumina to the base metal will notice that the surface structure of

the samples had been distorted by blisters with completely discolored.

- 10- Improved surface finish, finer grain size, better soundness at the surface, and adjustments in heat treated condition may all contribute to the fatigue behaviour resistance.

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