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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/Al_2O_3)

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A B S T R A C T

Aluminum alloys composite is one of the most common types of composite materials that are widely used in the recent years. This paper deals with the effects of the heat treatment techniques and some centrifugal casting parameters on the fatigue behavior of the composite material (A380/ Al_2O_3) for high-cycle fatigue resistance which is one of the most important properties for the automotive industry. Aluminum alloy A380 is used with alumina particles Al_2O_3 to form a composite material through the process of centrifugal casting. The proportions are 10% and 20% with a grain size 63µm. Then, thirty-two models of composite material (A380/Al_2O_3) have been manufactured. 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. Adding 10% alumina to the composite material causes distortion of the surface structure samples which marked by blisters and are completely discolored. A high Alumina content improves the fatigue behavior of the composite material (A380/ Al_2O_3).

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تأثيرات تقنية المعاملة الحرارية (T6) وبعض العوامل المتغيرة لسباكة الطرد المركزي على تصرف خاصية الكلال للمادة المركبة (A380/Al_2O_3)

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 لسباكة الطرد المركزي على تصرف خاصية الكلال للمادة المركبة (A380/Al_2O_3) وذلك لان خاصية الكلال واحدة من أهم الخواص التي تدخل في صناعة السيارات. استخدمت سبيكة الألمنيوم A380 مع جسيمات الالومينا Al_2O_3 وبالنسب (10% و20%) ذات الحجم الحبيبي (µ63) وذلك لتكوين المادة المركبة عن طريق عملية السباكة بالطرد المركزي. على كل حال، تم تصنيع اثنان وثلاثون عينة من المادة المركبة (A380/Al_2O_3) أعلاه، حيث أن نصف النماذج اجري عليهم فحص الكلال مباشرة والنصف الأخر أجريت له المعاملة الحرارية (T6) وبعد ذلك اجري لهم فحص الكلال أظهرت النتائج إن إضافة كمية من الالومينا وبنسبة 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 وجود مسامات صغيرة يصاحبها تغير اللون السطح الخارجي للعينات عند فحصها مختبريا. وأخيرا، تم استخدام كمية كبيرة نسبيا من الالومينا وذلك لزيادة مقاومة المادة المركبة للكلال.

1. 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 features gradual compositional variations from concentrated metal region at one surface to ceramic concentrated region at the other,

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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 complieated 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 such as 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 that is usually associated with obtaining of functionally graded materials mainly composite materials and 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 the morphology factors such as volume friction, 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 that 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. Soppa 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 deal with three tasks first is adding 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.

2. THE EXPERIMENTAL WORK

2.1. 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 particles that distributed in the matrix. This material has been fabricated via metallurgical route when the material was melted at 750℃ inside in the electrical furnace and poured into the permanent die which was previously preheated at 450℃. After that, Al380/Al_2O_3 extruded to the required specimens and heat treated in a certain method to achieve fatigue behavior.

Alumina particles are used as a strengthening. This alumina of purity 99.9% from the production company (Panreac) and a molecular weight 101.96, as controlling the particles grain size by a group of a vibratory sieve contain small holes of ranging size 63 microns. A cleaned metal base, which is a cover of the internal combustion engine cylinder of Toyota car type CZK Model (1980-1981). After the removal of grease, it was cut into pieces weighing 2 kg with the removal of all the accessories that their chemical composition was altered. They formed the metal that required for the foundation and were subsequently used to create a melting furnace. Control of the required melting molding temperature is done using a digital control system. Note that the chemical analysis of alloy (spectral analysis) was conducted in Al Nasr General Company, Table 1 shows the chemical composition of the base alloy that used in this study. In order to determine the appropriate conditions for the production of composite material that consisting the base alloy (A380) and alumina particles, studying the following variables is essential:

1- Pouring and Die temperature.
2- Rotational speed of the die.

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

The operation is done by placing the metal parts in the ceramic crucible with Carbide silicon and then they are placed in the furnace where temperature is digitally controlled to reach 750C° then 1% slag of German remover type (KALF4) is added to a high-density molten aluminum alloy (A380) 2.71g/cm^3 where it is mixed with molten metal by ladle iron hand. The removal of the slag is conducted by ladle [18]. Later, (3.97 - 3.986) g/cm^3 density and imperceptibly alumina particles are added to the center of the vortex. The volumetric proportions of the particles amount is 10% and 20%, where they are mixed with a molten metal by 500 r/min electrical stirrer.

The initial process of mixing continues for one minute and then the furnace temperature is raised to meet the required pouring phase. The furnace temperature now is stabilized in order to maintain the mixing process to the second stage. The mixing time ranges between (1-2 minutes) and at the same primary rotational mixing speed. The mixture is poured then into horizontal centrifugal molding machine. After that we take the product out and make 32 samples for the fatigue behavior examination in the CNC machine as shown in Figs. 1 and 2.

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

2.2. Testing Machine

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

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

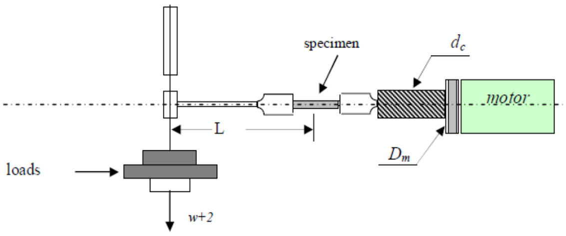

Fig. 3. Fatigue testing machine.

2.3. Applied Stress Calculation

From Fig. 3; Motor speed, ω_m = 1425 rpm means diameter of the motor pulley = D_m = 73 mm. Means diameter of the chuck pulley = dc = 36.5 mm.

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

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 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.

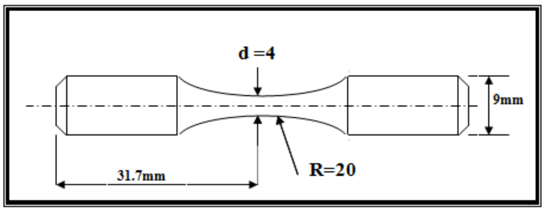

Fig. 4. The dimensions of fatigue test specimen.

Preliminary heat treatment experiments were performed using 32 specimens of composite alloy (A380/Al_2O_3). The chemical compositions are listed in Table 1. Composite material was used to produce a standard fatigue specimen, Figs. 1 and 2. The fatigue specimen was subjected to a 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 505 °C and the samples were then quenched in the natural aging, for 3 hours at 155 °C and their room temperature fatigue properties was measured.

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

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

- Increase hardness of improve machinability.
- Increase strength and/or produce the mechanical properties that associated with a particular material condition.
- Stabilizing the mechanical and physical properties.
- Ensure that the dimensional stability as a function of time under service conditions.
- Relieve residual stresses that 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 down to room temperature and then to be heated again to 155 °C for (3) hours in order to obtain an artificial aging as shown in Fig. 5.

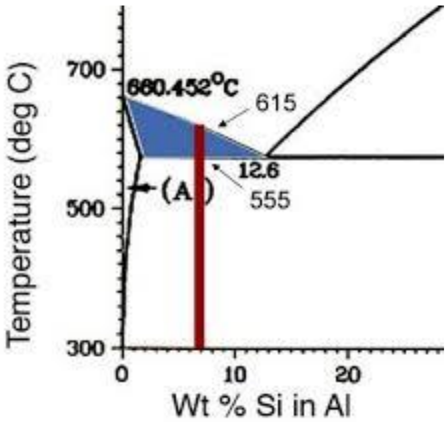

Fig. 5. Portion of Aluminum-Silicon binary phase diagram.

3. RESULTS AND DISCUSSION

The effect of the amount of alumina on the microstructure is shown in Figs. 6 and 7 which present the effect of alumina particle size on the microstructure. After the heat treatment solution (T6) to 505 °C for 8 h then precipitation is applied at 155 °C for 3 hrs . A high degree of reinforcement and 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.

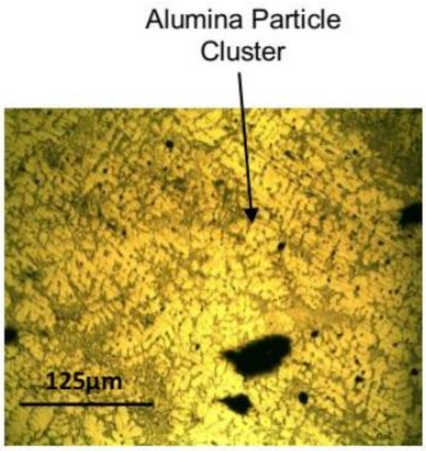

Fig. 6. The shape and size of clusters alumina particles with morphology phase eutectic when alumina ratio of 10%.

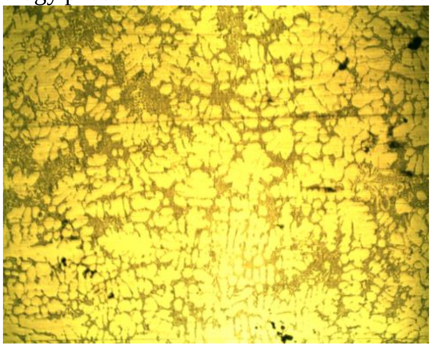

Fig. 7. The shape and size of clusters alumina particles with morphology phase eutectic when alumina ratio of 20%

To study the heat treatment T6 effect on some samples, which were used to examine the fatigue behavior, an electrical furnace was used so this composite alloy ($A380/Al_2O_3$) to a temperature of 505. Figs. 3(a) and (b) show the difference in the structure of the outer surface of the samples some of which clearly show blisters on the surface and negative fatigue behavior. The specimens is completely discolored and many blisters are observed on the surface as shown in Fig. 8(a). On the other hand, the surface of remaining samples is not affected by heat treatment and their fatigue property is virtually unchanged as shown in Fig. 8(b).

(a) (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 that added to the alloy of aluminum (A380) as increasing this percentage up to 20%, this may help to prevent the appearance of blisters in the structure of the outer surface of the samples. In general it could be said that 20% is better than 10% when heat treatment solution is used as shown in curves at Figs. 9 and 10. From the above, it could be concluded that the alumina particles did helped to rising the temperature range of the heat treatment solution in addition to its ability to improve the strength, hardness, wear resistance, corrosion resistance and increasing the matrix fatigue life. A cording to these results, it is clear that the centrifugal technique is substantially improves the mechanical and fatigue properties of the material.

4. CONCLUSIONS

The main conclusions may be drawn:

1- A proper solution and precipitation temperature results in improved fatigue properties, however, excess heat treatment conditions deteriorate the fatigue properties to grain growth and reduce hardness.

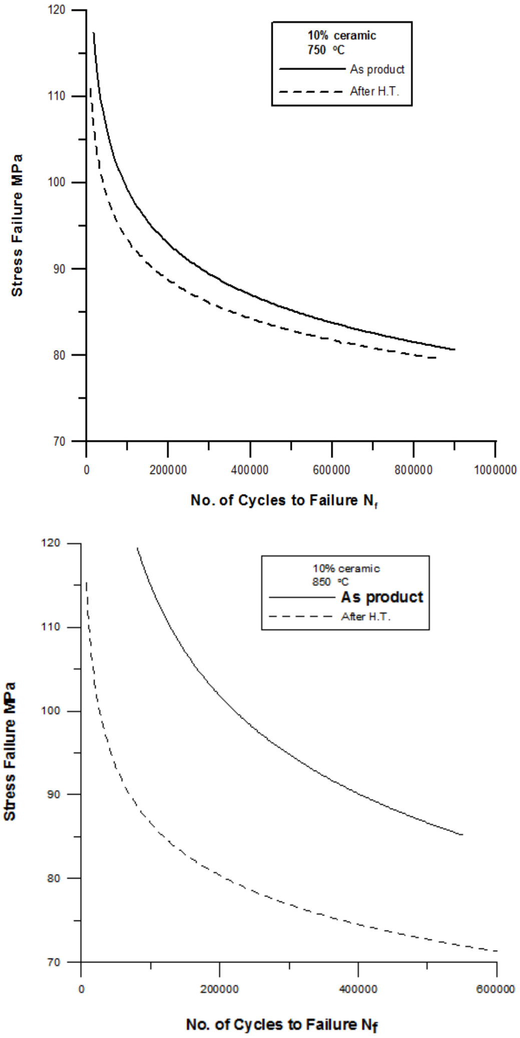

Fig. 9. Fatigue curve for the composite material $A380/Al_2O_3$ with 10% ceramic at 750 and 850°C.

2- Addition of alumina, considerably improves the fatigue properties of aluminum alloy A380 in all fatigue test distances. Addition of 20wt.% alumina improves the fatigue properties. For example, the fatigue rate is decreased by 17% if alumina particle ratio is reducing from 20 to 10wt%.

3- Elevates temperature to 505 °C helps reducing relative porosity and enhancing densification, whereas keeping solution time to 8hrs leads to grain coarsening.

4- High amounts of alumina lead to reduce the relative porosity and, large alumina size and this initially raises the relative density and drops it later.

5- Increasing the amount of alumina promotes 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.

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

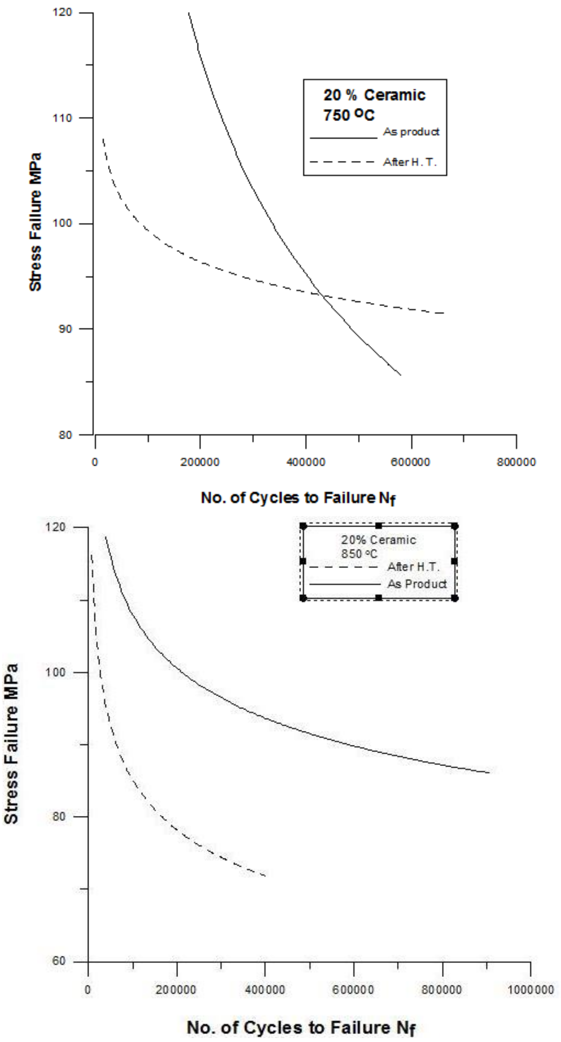

Fig. 10. Fatigue curve for the composite material A380/Al_2O_3 with 20% ceramic at 750 and 850 ℃.

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