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STUDY THE EFFECT OF ADDING ASTEEL POWDER ON MECHANICAL AND THERMAL PROPERTIES OF SINTERED (ALUMINA-STEEL) COMPOSITE MATERIAL

Dr. Sahira Hasan Ibrahim [1], Sahar Hussein Ahmed [2], *Iman Ahmed Hameed[3]

1) Lecturer, Mechanical Engineering Department, University of Technology, Baghdad, Iraq.
2) Assist Lecture, Mechanical Engineering Department, University of Technology, Baghdad, Iraq.
3) Engineer, Mechanical Engineering Department, University of Technology, Baghdad, Iraq.

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Abstract: Alumina is one of ceramic materials that used for the high-performance applications, such as: (chemistry, health, medical, electrical insulator, refractory uses and others). In this study, the carbon-steel powder has been added to Alumina powder with a weight ratio of (1:1). The mechanical property (compressive strength) and thermal conductivity have been investigated experimentally for a composite material sintered at five different temperatures (1100, 1200, 1300, 1400, and 1500) °C. From the results obtained there is an increasing in compressive strength and thermal conductivity of the composite material for temperature range of (1200 to 1400)°C, comparing to pure alumina, in which both compressive strength and thermal conductivity were increasing with sintering temperature , but in values less than for composite. This indicated that adding the metal powder enhances the mechanical and thermal properties for solid state temperature of the two materials.

Keywords:*Alumina powder, steel powder, composite material, sintering, compressive strength, thermal conductivity.*

دراسة تأثير اضافة مسحوق الفولاذ على الخصائص الميكانيكية والحرارية للمادة المتراكبة (الألومينا –فولاذ)

الخلاصة: الالومينا احدى المواد السيراميكية التي تستخدم في مختلف التطبيقات بسبب خواصها العالية الاداء مثل (الكيمياء , الصحة و الطب , العوازل الكهربائية , الحراريات واخرى) . في هذه الدراسة تم اضافة مسحوق (الصلب الكاربوني) الى مسحوق (الالومينا) بنسب خلط وزنية (1:1) . تم دراسة الخاصية الميكانيكية (مقاومة الانضغاط والموصلية الحرارية للمادة المتراكبة الناتجة) وعند خمس درجات حرارة تلبيد مختلفة هي (1500,1400,1300,1200,1100) م˚ .واشارت النتائج الى ان هناك زيادة في مقاومة الانضغاط والتوصيلية الحرارية للمادة المتراكبة عند درجات حرارة تتراوح بين(1400,1200) م˚ ,وعند مقارنة مقاومة الانضغاط والموصلية الحرارية للالومينا النقية وجد ان الزيادة اقل ,وهذا يشير الى ان اضافة المسحوق المعدني قد حسن الخواص الميكانيكية والجرارية ولكن بحدود درجات حرارة التلبيد ضمن الحالة الصلبة لكل من المادتين.

1. Introduction

Metal matrix composites (MMC) have received substantial attention due to their reputation as stronger, stiffer and lighter materials over the base-alloy. Composite

*Corresponding Author az_naji@yahoo.com

materials or simply composites are combinations of materials that made up by combining two or more materials in such a way that the resulting materials have certain desired properties or improved properties. The application of MMC and composites is mostly in aerospace structures, cutting tools and automobile engine parts. Currently, the major reinforcements added to improve combination of properties are ceramic particles with high mechanical properties, i.e. Al_2O_3, TiC, TiB_2, and SiC, etc. Alumina is an extremely useful ceramic in many existing and emerging technologies.

It has several special properties like high hardness, chemical inertness, wear resistance and a high melting point. Alumina ceramic can retain up to 90% of their strength even at 1100 ºC [1]. The most majority application of alumina is the production of aluminum, others include electrical insulator, bio-medical implants, filler, catalysis, purification, composite fiber, abrasive. High density in Alumina components is normally achieved by sintering compacted Alumina powder above 1700ºC [2], there are many researches dealing with Alumina and the effect of sintering on mechanical and thermal properties.

J. S. Forrester et al, 2008 [3] studied the effect of mechanical milling on the sintering behavior of Alumina and found that a significant reduction in sintering temperature to below 1200ºC was realized, the powder can be sintered into dense ceramics much below the normally required sintering temperature of 1700ºC. P Ching Yu and F Su Yen, 2010 [4] investigated high pure Alumina at sintering temperature 1400 ºC, and S. Müller et al, 2011 [5] the fractional porosity of the powder metallurgy component is being derived from the sinter density and also observed the hardness variation of the same with respect to sintering temperature.

Mehdi Rahimian et al, 2014 [8] investigated the effect of alumina particle size, sintering temperature and properties sintering time on the properties of Al–Al_2O_3 composite, where the variations in of Al–Al_2O_3 composite are dependent on both sintering temperature and time. Prolonged sintering times had an adverse effect on the studied the mechanical and tribological behavior of composites reinforced with silicon or hard ceramic particulates (e.g, Alumina, Zirconium Silicate, Fly Ash), the wear resistance was evaluated during sliding against hard steel under lubricating conditions at elevated temperatures.S. Zhang et al, 2011 [6] studied the influences of filler size and content on the properties (thermal conductivity, impact strength and tensilestrength) of Al_2O_3/high density polyethylene (HDPE) composites.

Goutam Dutta and Dr. Dipankar Bose, 2012 [7] studied the porosity variation of a powder metallurgy component with respect to its sintering temperature is explored where strength of the composite.The introduction should set the tone of the paper by providing a clear statement of the study, the relevant literature on the study subject and the proposed approach or solution. The introduction should be general enough to attract a reader's attention from a broad range of scientific disciplines.This template, created in MS Word 2003/2007 provides authors with most of the formatting specifications needed for preparing their papers. Margins, line spacing, and typestyles are built-in; examples of the type styles are providedthroughout this document.

2.Experimental Procedure

The second step to prepare compos the materials that used to make the composite material were consisting of two commercial powder metals, [alumina and carbon-steel]. The two powders were dried in oven at 100 ºC for one hour and then weighed, first step to prepare samples of alumina powder, (20g) weighed and mixed with polymer binder to made two samples for each sintering temperature.The material, (10 mg) from each one were mixed in a powder blender (Ball Miller 9VS) for 30 min, (20gm) of mixture were mixed with (3% ml) of polymer binder (PVA) to provide strength of combination, a die that given a dimension of (30 mm) diameter , (10-15) mm of height was selected was shown in fig1, and sample pressed in hydraulic pressure with (5 ton) load shown in fig1,the samples have been produced in circular shape with dimension (30.2 mm diameter, 13.6 mm high), and (20.6 mg) weight.. The alumina samples and composite material was shown in Fig. 2

Figure1. Hydraulic Pressure & Die

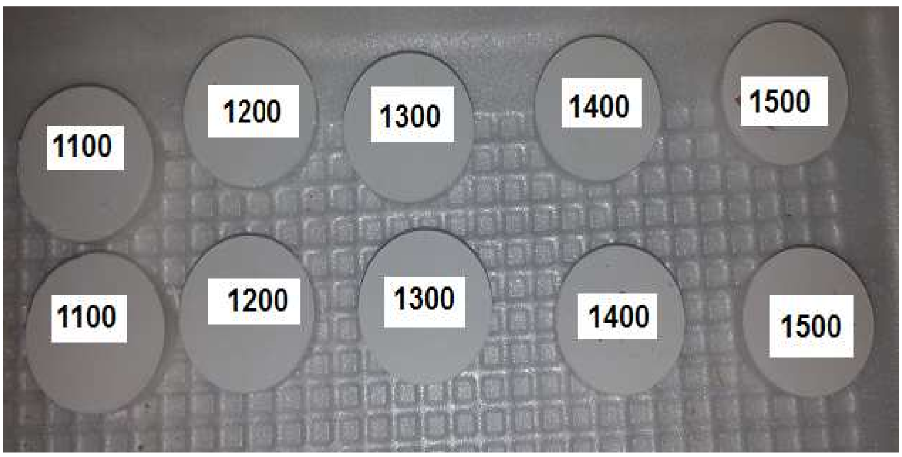


Figure 2. Alumina Samples before Sintering

The sintering process was done in electrical furnace at (1100, 1200, 1300, 1400, 1500) °C, with temperature rising rate (10 °C /min) and holding time (1 h), the Alumina and composite samples shown in figs 3,4. The sintering conditions listed in Table1.

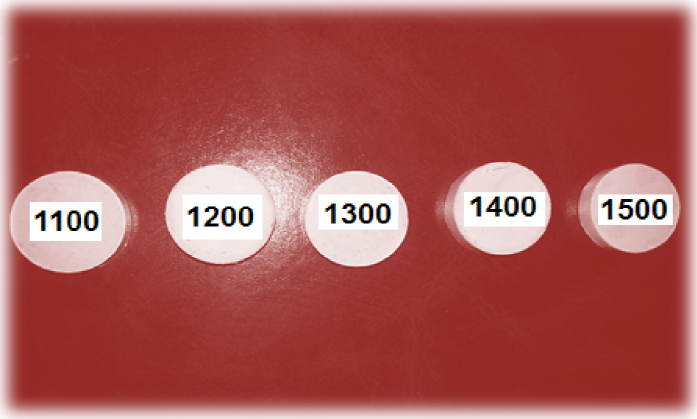


Figure 3.Alumina Samples at Different Sintered Temperatures

Figure 4. Composite Samples at Different Sintered Temperatures

Table1: Sintering Conditions

Sintering state time (hour)	Sintering rate (°C/min)	Sintering temp (°C)	Sample (No)
1	1100	10	1
2	1200	10	1
3	1300	10	1
4	1400	10	1
5	1500	10	1

3. Mechanical Test

The compressive strength test has been applied for the five Alumina samples and composite material by using the universal testing machine shown in fig5, which gives the (stress-strain) values for the Alumina and composite specimens sintered at different temperatures**.**

Figure 5. Universal Testing Machine

The average values obtained for compressive strength for alumina are (0.67MPa, 0.24MPa, 0.51 MPa,0.96MPa, and 1.15MPa) at sintering temp (1100°C,1200°C,1300°C,1400°C,and 1500°C),respectively.The average values for composite material are (1.77MPa, 28.96MPa, 31.77MPa, 36.20MPa, and 1.61MPa) at sintering temp (1100°C,1200°C,1300°C,1400°C, and 1500°C). The test diagrams are shown in figs (a1-a5).

4. Thermal Test

The Hot Disk TPS is the flagship instrument in the system portfolio of Hot Disk AB. This instrument is designed for precision analysis of thermal transport properties, including thermal conductivity, thermal diffusivity and specific heat capacity, and it covers an extensive range of materials of various geometries and dimensions. The device is shown in fig6, and it gives the values of thermal conductivity for alumina and composite material specimens sintered at different (temperatures-time).

Figure 6. Hot disk TPS

The average thermal conductivity for pure Alumina are (2.01W/m.K, 0.207 W/m.K, 0.59 W/m.K 0.85W/m.K, and 1.76W/m.K), at sintering temp (1100°C,1200°C,1300°C,1400°C,and 1500°C), respectively. The average thermal conductivity for composite are (0.6228 W/m.K,1.58 W/m.K,1.31 W/m.K, 1.24 W/m.K, and 0.523 W/m.K, at sintering temp (1100°C,1200°C,1300°C,1400°C,and 1500°C),respectively. The conductivity values have been raised for the sintering temp range of (1200 to 1400) °C, and then reduced at 1500°C. The test diagrams are shown in figs (b1-b5).

5. Results and Analysis

The results of compressive strength that obtained for composite material at different sintering temperature are listed in Table 2.

Table 2: Compressive Strength Results

Sample (no)	Sintering temp (°C)	Compressive strength Alumina (MPa)	Compressive strength Composite (MPa)
1	1100	0.67	1.77
2	1200	0.24	28.96
3	1300	0.51	31.77
4	36.20	0.96	36.20
5	1.61	1.15	1.61

From the data above (Table. 2), the compressive strength for pure alumina obtained from test begin at (0.67 W/m.K at 1100°C), (0.24 W/m.K at 1200°C), (0.51 W/m.K at 1300°C), (0.96 W/m.K at 1400°C), and (1.15 W/m.K at 1500°C). and when the steel powder added to alumina to made composite material samples, it was observed that, the composite strength at (1100 °C) was increased due to add the steel particles that increased the strength of composite, and with increasing sintering temperature from (1200°C - 1400°C), the strength increases sharply, because the total fractional porosity of powder metallurgy process is decreasing with the increase in sintering temperature [7]. The comparing between two cases was shown in fig 7. It can see that the steel powder filled the pores and as sintering temperature increase the particle size for alumina reduced and density at first raises, then declines. As the Alumina particle size decreases, hardness, yield strength, compressive strength and elongation increase [8].

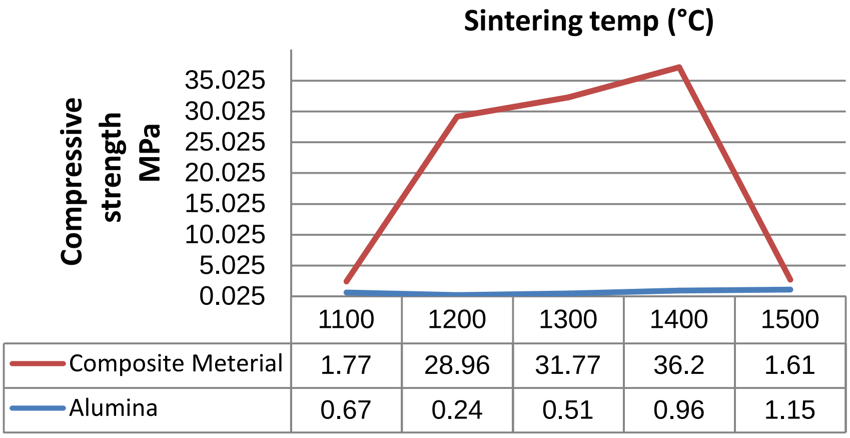


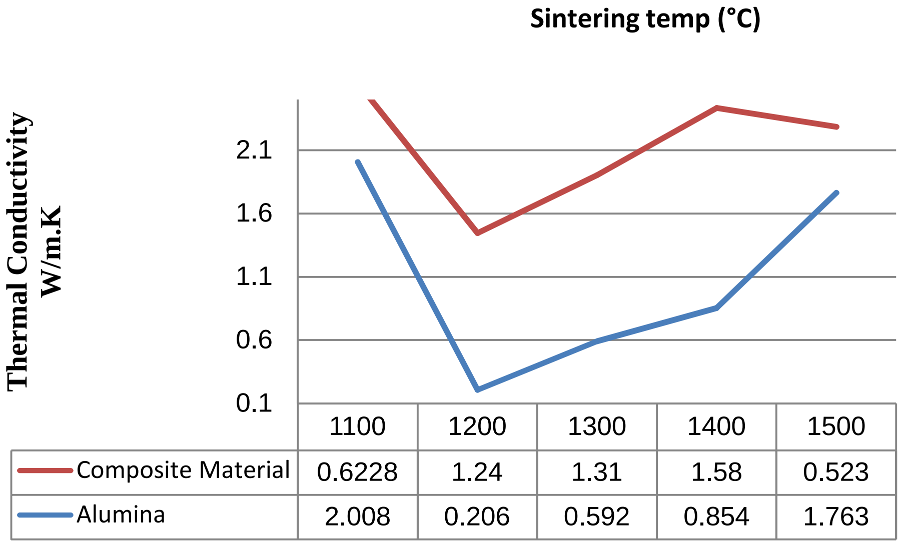
Figure7. Compressive Strength Diagram

From the diagram, it’s found that strength for composite material in range (1200-1400) °C increase with sintering temperature increasing, however, the strength of Alumina is statistical quantity with a wide scatter due to the low toughness and depends on stress volume also Alumina particles become more dispersed, the microstructure shown in fig.10 (A-E), and they have more uniform particle size distribution [9].The thermal conductivity results are listed in Table3.

Table 3: Thermal Conductivity Results

Sample (no)	Sintering temp (°C)	Thermal Conductivity Alumina W/m.K	Thermal Conductivity Composite W/m.K
1	1100	2.008	0.6228
2	1200	0.206	1.24
3	1300	0.592	1.31
4	1400	0.854	1.58
5	1500	1.763	0.523

The thermal properties for alumina were a function of temperature; it decreases with increasing of temperature, and the compare between the Alumina and (Alumina-steel) is shown in fig 8.



	1100	1200	1300	1400	1500
Composite Material	0.6228	1.24	1.31	1.58	0.523
Alumina	2.008	0.206	0.592	0.854	1.763

Figure 8. Thermal Conductivity Diagram

From the diagram it can be seen that thermal conductivity for Alumina alone decreasing at 1100°C and then raised with sintering temp increasing, while the (Alumina-steel) increasing at temperature (1200-1400) °C, this due the steel particle distribution between alumina ,the microstructure shown in fig .9(A-E) .

6. Conclusions

1. The compressive strength for composite (alumina-steel) increased with temperature increase between (1200-1400) °C.
2. The thermal conductivity decreased at 1200°C then increased with sintering temperature increased.
3. The pure alumina has increased but less than composite material when compared with the results obtained, where the added of steel powder has improved and gives a new product.

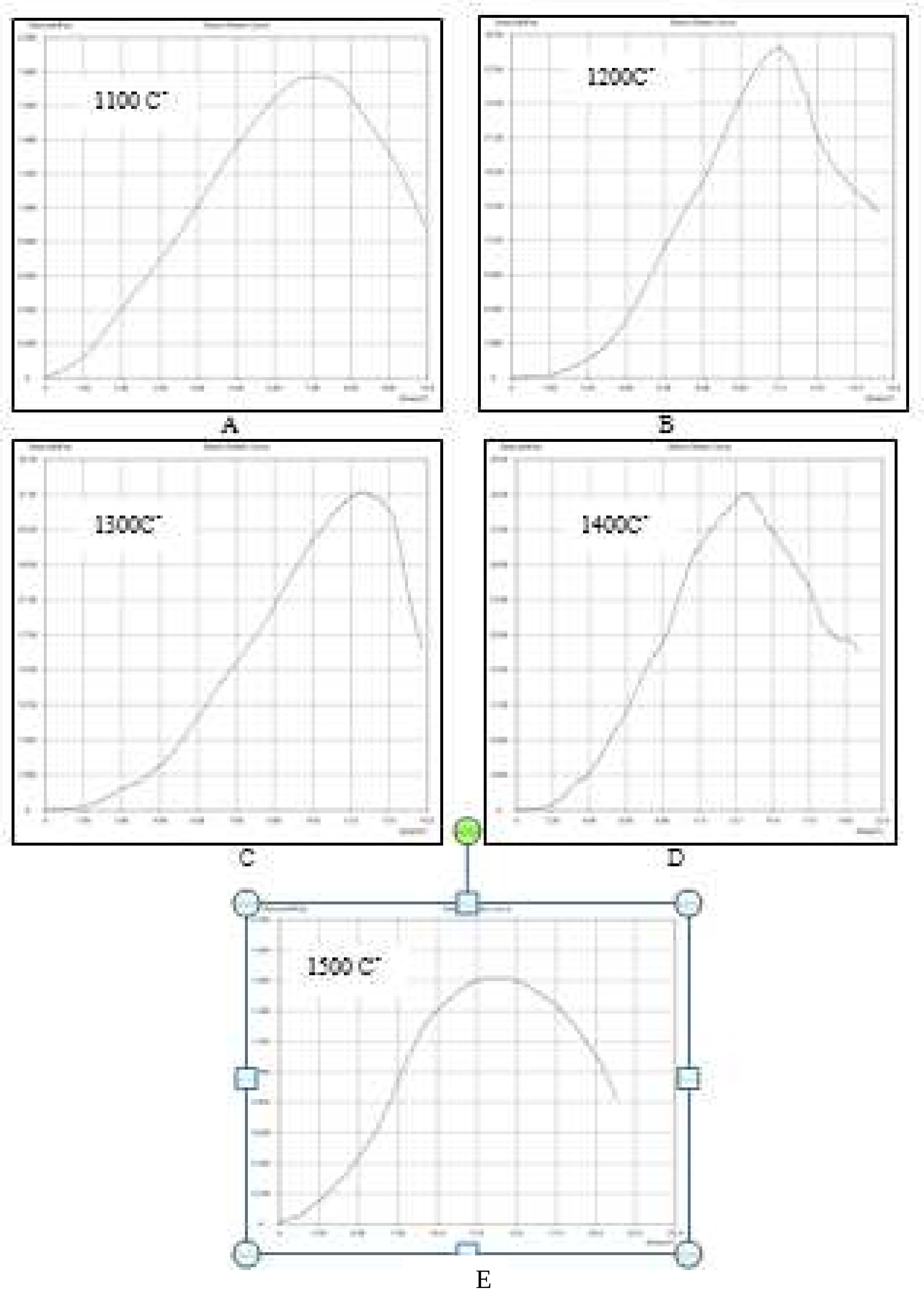
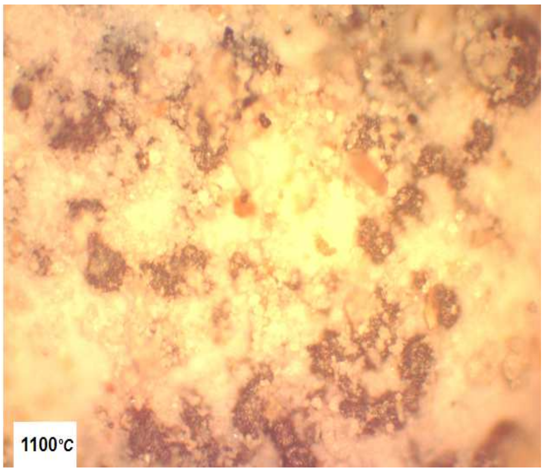
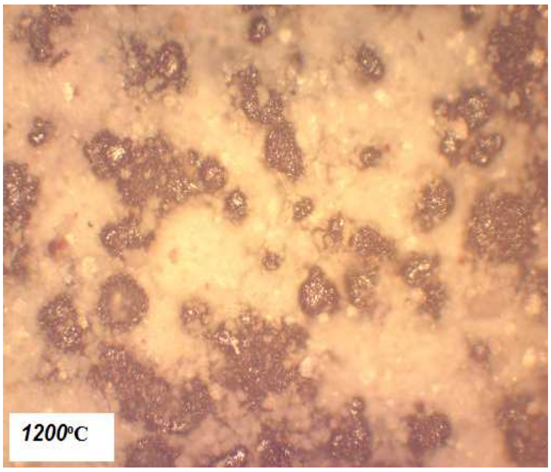


Figure 9. Stress-Strain Curves at Different Sintering Temp



A



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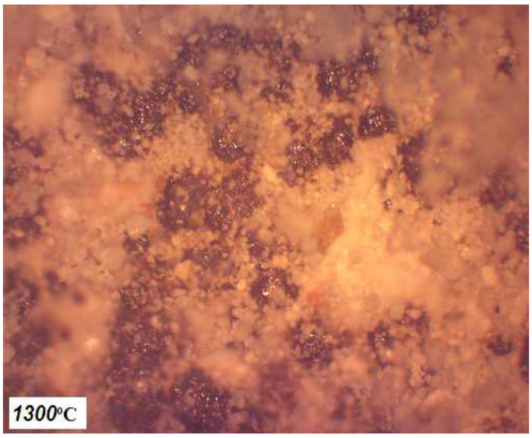

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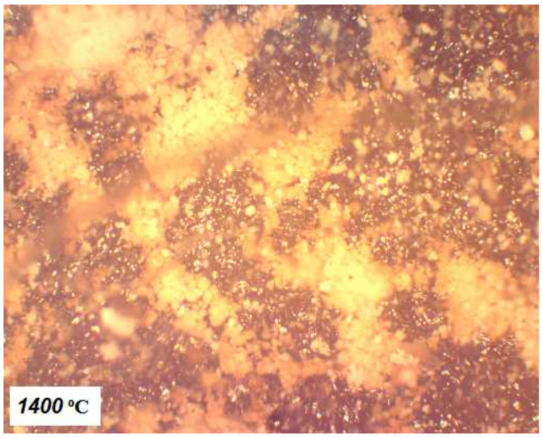

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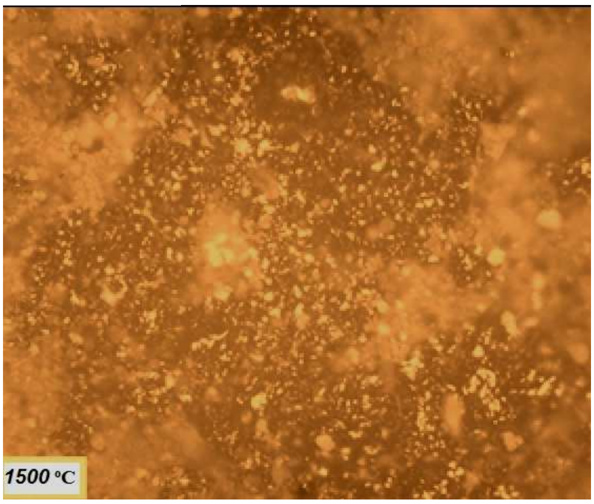

E

Figure10. Microstructures of Composite at Magnification of 10X

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