Silicon Carbide particles dispersion Effect on the sintering behavior and damage characterization of Yttrium Oxide Composites Ceramics

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Abstract: Yttria, silicon carbide powders of (99.99) purity having (40-60) µm grain size were used to form different milling were done for all the combinations at 12 hours. Samples of disc shape were fabricated and sintered at different sintering temperature (800, 1000, 1200 and 1400) °C, respectively under static air and for three hours as soaking time. XRD test reflect the formation of new phase which is Y₅Si₃C (Unique). SEM test shows the sintering behavior after the sintering process. Sintered samples were mechanically tested by hardness and fracture strength. Improvement was noticed for all the combinations after adding the dispersed SiC particles detected especially at the combination (Y₂O₃ 80-SiC20) Wt.%, sintered at 1400 °C.

Keywords: ceramic composites, Sintering, Hardness, Fracture strength.

1. Introduction

The composite materials mainly consist of two or more than material can be intimately bonded to have a new material with unique properties compared with their consistent. As all composites ceramic materials, yttria–matrix composites can be tailored. By addition of high strength, high temperature resistance, high hardness to get attractive properties with the ability to operate under high temperature. Silicon carbide is a filler material can be use successfully due to its excellent properties such as high thermal conductivity, low coefficient of thermal expansion, high modules and low density [1]. Chemical properties reflect its high stability during synthesis under severe conditions. SiC particles can be used with other materials, like metals Al-SiC metal matrix composites [2]. Yttria in recent twenty years received many scientific attention in many fields, because of its excellent properties such us high dielectric constant, low absorption in broad range (near UV to IR), superior electrical brake down voltage and low leakage current [3]. Yttrium occurs in nearly all of the rare-earth minerals. It is recovered commercially from monazite sand, which contains about 3%, and from bastnasite, which contains about 0.2%. The metal is now produced mainly by reduction of the fluoride with calcium metal. Yttrium oxide is one of the most important compounds of yttrium and accounts for the largest use. It is widely used in making YVO₄ europium, and Y₂O₃ europium phosphors to give the red color in color television tubes. Many hundreds of thousands of pounds are now used in this application. Yttrium oxide also is used to produce yttrium-iron-garnets, which are very effective microwave filters. It also has potential use in ceramic and glass formulas, as the oxide has a high melting point and imparts shock resistance and low expansion characteristics to glass. Hard, dense layers are deposited by electron-beam evaporation sputtering. Typical applications are protection of aluminum and silver mirror coatings, intermediate layer in wide band visible AR coatings and for XeCl (308 nm) laser AR and dielectric mirror designs. Yttrium oxide is the thermodynamically most stable oxide and is suitable for extreme operation conditions. It is used as a coating in metal production. Yttria is often used with zirconia to form yttria Stabilized Zirconia (YSZ).
Yttria has the common characteristics of ceramics that are not found in metallic or organic materials, including high hardness (Next to Diamond), high mechanical strength, high temperature stability, chemical resistance, erosion resistance, low electrical conductivity. Many researchers study the sintering behavior of yttria, E.KOSTIC, M.M.RISTIC, mentioned the powder activity from 1000 °C to 1400 °C, while Marlowe and Wildwer study the densification from 670 to 1600 °C [4]. However, as a ceramic material, both yttria and SiC is brittle and its mechanical strength is considered to be less than that of other metal carbides. Aside from that, SiC is susceptible to chipping and fracture when introduced to large mechanical stress or shock. Another disadvantage of SiC is that the material is difficult to be manufactured in any required shapes especially for component design for certain application. Moreover, it is difficult to density the SiC without the use of suitable additives and external pressure [5]. This is mainly due to the covalent nature of silicon carbon (Si-C) bonding together with its low self-diffusion coefficient. Among common sintering aids to obtain a dense silicon carbide are aluminum oxide (Al2O3), yttrium oxide (Y2O3) and boron oxide (B2O3). As experimentally investigated by Omori and Takei [6], β-SiC could be densified by sintering at the temperature of 2100 °C using yttrium oxide and aluminum hydroxide. In the present work our goal is to study and improve the sintering behavior and the mechanical properties for the yttria after adding silicon carbide as dispersed particles under elevated temperature.

2. Experimental details

2.1 preparation of Y2O3- SiC composites ceramic material .

High purity yttria and silicon carbide of 40 µm , were used to fabricate the composites ceramics. Different weight percentage ranging (5,10,15,20) SiC were dry mixed with the matrix yttria at soaking time 8 hrs. Discs of 2 cm in diameter were compacted to be ready for sintering process. Different sintering temperatures used under static air, gradually from (800,100,1200, and 1400 )°C. The sintered bodies of three samples from each combination are ready to further tests.

2.2 Characterization of samples

The fabricated samples were measured its sintered density(Bulk density) , by the geometrical method using high accurate electronic balance and high accurate digital micrometer and according to the ASTM C29/C29M-17a. X-ray diffraction have been done by using (6000-Shimadzu) with wavelength λ=0.15418 nm. Scanned from the two theta degree (20-70) to identify the resulting crystal structure.

The damage characterization for each combination after sintering was observed by applied the Vickers hardness test and fracture strength respectively. By using high accurate instruments having a well calibrated test (± 0.1) tolerance in measurements.

3. Results and discussions

3.1 Characterization

The investigated XRD pattern for each combination after sintering process was discussed. The most attractive and unique one shown in figure 1 , which indicate the domain phase No.1, belong to the yttria [7], while the most second domain phase is No.3, belongs to the new phase formation Y5Si3 (File 00-038-0794). And the silicon carbide phase [8], was also detected and signed by No.2, in all sintering temperature.

More over silicon oxide phase [9], also signed by No.4 Wt.%, at sintering temperature 1200 °C and1400 °C. The new phase No.3, was generated at sintering temperature 1400 °C, and it was very clear can be signed in all the combinations, and its intensity increased as increasing in the SiC added weight percentage, reaching its maximum at the 20 Wt.%.
Figure 1: XRD pattern for the ceramic composite materials, sintered at 1400 °C, under static air for 3 hours, no.1 (Y2O3), no.2 (SiC), no.3 (Y5Si3), no.4 (SiO2).
The sintered density relation with the added silicon carbide shown in figure 2. The increasing in sintering density was noticed for all combinations comparing with its value regarding the matrix (Yttria). Starting from (SiC 5 Wt.%), with highly increased value reflect the first sintering stage and overlapping with the second sintering stage at the (SiC 10,15 Wt.%) . While the best results can be shown at the sintering temperature 1400 °C, and especially for the combination (Y2O3 80-SiC20)Wt.% , reached the maximum value 2.570(gm./cm3) which represent the final sintering stage . This increasing in sintered density is due to the best homogenization done between the yttira and silicon carbide powder [10] , which lead to increase the powder activity of the matrix [11], and the formation of liquid phase [12].

![Figure 2](image)

**Figure 2**: Sintered density for the composites ceramics (Y2O3-SiC) sintered at different temperatures under static air for 3 hours.

At sintering temperature 1200 °C as shown in figure 3, the scanning electron micrograph which indicate the SiO2 as the liquid phase [13]. And at 1400 °C, the three sintering stages[14] as shown in figure 4, (A, B, C) the scanning electron micrographs of the composites ceramic material. Where (A) is the first stage of grain contacting, (B) the second stage of grain growth with open porosity, and (C) the third stage (final stage) of mass transportation with closed porosity.

![Figure 3](image)

**Figure 3**: SEM micrograph for the composites ceramics (Y2O3 80 SiC 20)Wt.% , sintered at 1200 °C under static air for 3 hours.
Figure 4: SEM micrograph for the composites ceramics (Y2O3 80 %-SiC 20 %) Wt.% sintered at 1400 °C under static air for 3 hours. A) First stage, B) Second stage, C) Third stage of sintering.

Hardness test can clearly be shown for all the fabricated composites ceramic Y2O3- SiC, the increasing in hardness after adding the dispersed silicon carbide particles sintered at different sintering temperature under static air was observed at all the combination and at all sintering temperature reaching its maximum value of 380Mpa at the combination (Y2O3 80 % - SiC 20%) Wt.% sintered at 1400 °C as shown in figure 5. The increasing in hardness can be translated to the improvement in the sintered density coupled with increasing in silicon carbide dispersed particles, that reflect the matching in two materials to have the final product with hard and uniform shape after the mass diffusion settled during the final stage of sintering [15].
Figure 5: Hardness for the composites ceramics (Y2O3-SiC), sintered at different temperatures under static air for 3 hours.

From figure 6, which represent the fractural strength for all combinations after sintering with respect to the added silicon carbide particles, the increasing in fractural strength started slowly with little increasing at the combination Y2O3 95Wt.% - SiC 5Wt.% , and at all the sintering temperatures ,while at the combinations Y2O3 90Wt.% , Y2O3 85Wt.% and Y2O3 80Wt.% the increasing marked as gradually until reach the maximum value of 4.8Mpa at the sintering temperature 1400°C. This behavior is well consistency with the sintered density and hardness results, which is commonly reflect the effect of the silicon carbide particles dispersion manner within the matrix [16].
4. Conclusions

The effect of added dispersed silicon carbide particles of (40-60) µm was shown at all the fabricated compacted composites ceramics sintered at different sintering temperatures ranging from (800, 1000, 1200, 1400) ºC, under static air for 3 hours. The phases presents and the unique one (Y₅Si₃) is indicated too. Clear improvement in sintering density was noticed. More over, the damage characterization were achieved by investigated the hardness and fractural strength, which reflected the improvement for all the fabricated combinations. The best results signed at the combination (Y₂O₃ 80-SiC 20) Wt.% , sintered at 1400 ºC, under static air for 3 hours.

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