International Journal of Innovative Technology and Interdisciplinary Sciences
www.IJITIS.org
ISSN:2613-7305
Volume 3, Issue 4, pp. 513-520, 2020
DOI: https://doi.org/10.15157/IJITIS.2020.3.4.513-520
Received September 6, 2020; Accepted October 18, 2020

Fabrication of the Ti/SiC Based Composites by Self-Propagating High Temperature Synthesis

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ABSTRACT

Metal matrix composites (MMC) consists of matrix and reinforcement. Aluminium (Al) and titanium (Ti) are mostly used as a matrix, while ceramics like silicon carbide (SiC) play role as a reinforcement where magnesium (Mg) act as wetting agent. Al/Ti alloys often used in the applications of powder-shaped. Nevertheless these materials are very suitable for the processes that are using a simple and novel method called self-propagating high temperature synthesis (SHS). Based on it, some of the advanced materials such as alloys, advanced ceramics and intermetallic compounds have been focused on SHS process. The SHS compacting process is carried out in stages according of the temperatures helping by compacting force applied. Our research work will be focused on the fabrication composites based Ti/SiC by using SHS process. The microstructure of the Ti/SiC based composites was investigated by using optical microscope. The micro-hardness testing device has been used to determine the mechanical properties of Ti/SiC based composites. The relationships between reaction of the Ti and SiC have been investigated to obtain the value of the composite properties and the bond between Ti and SiC. Ti/SiC based composites were obtained with improved properties.

Keywords: SHS Process; Metal Matrix Composites; Titanium; Silicon Carbide.

1. INTRODUCTION

Composite material is a combination of two or more materials that have different phases and different properties to form a material that has better properties than the constituent materials [1]. Composite materials have matrix, reinforcement and adhesive or wettability as an elements. Based on it, aluminium (Al) and titanium (Ti) are some elements that play a key role at above elements. Furthermore, in our previous research work at [2] we have seen some elements in ceramics like silicon carbide (SiC) and magnesium (Mg) that were acting as wetting of adhesives. Al and Ti have advantages in their use as a matrix. Al-alloys were often used in the commercial applications where the high strength to density ratio has been needed. In the powder form Al has been suitable to merge by another material. Also in the matrix position, Al based composites can be substitute by Ti based composites due to similarities in their characteristics [3-4].

Powder form materials are suitable at the processes where it has been used the self-propagating high temperature synthesis fabrication (SHS). The range of applications is very wide and it has been used to produce a different types of materials by including combination of ceramics and metals. Many of the researchers have been focused on SHS as a simply and novel method for developing advanced materials such as alloys, advanced ceramics, composites and intermetallic compounds [5-7]. Based on the process, SHS is a system that involves an exothermic combustion. Through this process we can obtained a higher purity of the product due to high temperatures. Furthermore, the volatile impurities will be removed as the wave propagates through the sample in a consequence of the high temperatures. After the initial ignition realised through external sources it has been seen the released heat from the reaction of metal powder (fuel) with oxygen (oxidizer) in the presence of other metal oxides and reaction was able to have self-regeneration while the high temperature should be sufficient for the synthesis of the desired ceramic product. [7-9].

This study compared the use of Ti/SiC based composites of metal matrix composites (MMC). From the previous results at [10] it has been investigated that Mg was a wetting agent for binding metal materials to ceramics. However, in this paper we have replaced Mg content by an exothermic reaction in the SHS process. It is expected that the Ti/SiC exothermic reaction can bind to form a composite compound with very good properties. In our research work we will be focused in the improvement of Ti-SiC based composites on MMC. The relationships between reaction of the Ti and SiC have been investigated to obtain the value of their composite properties and the bond between Ti and SiC. Based on the results of our research work we can predicted the mechanical and morphological properties of the MMC grains by making the combination of Ti and SiC through SHS process.

2. MATERIALS AND METHODS

The materials used are as follows; titanium (Ti) powder, silicon carbide (SiC) powder, Alumina (Al2O3). Materials used to support the process: bakelit, liquid alcohol and ethanol. The cluster division consisted of matrix, namely Ti and SiC as reinforcement. While others are supporting materials to accelerate the reaction of the MMC process by SHS.

2.1 Material preparation process

The process of making powder is done by machining. In the machining process it produces coarse particles, for which the milling process is carried out. The refining process is carried out in order to obtain a uniform powder distribution for sample making so that a solid sample will be obtained when the compacting process is carried out.

The requirement for powder refinement in the sample (80-360 µm) is to do this in a gradual sifting process based on the size adjusted to the size. After the crushing process is carried out, a finer powder size is obtained then the mixing process of the sample materials used is carried out, this mixing process aims to homogenize the powders so that a solid sample can be obtained. The solid sample of Ti material is a matrix material that is prepared for integration with SiC as a reinforcing agent. The experiment does not use a wetting material such as Mg, Ni or the like.

The aim is to analyze the role of the exothermic heating of the SHS, whether it is optimal enough to produce a composite semi-reaction.

2.1.1 Powder weighing process

The weighing of the powder is adjusted to the size of each determined volume fraction, while the volume fraction taken is as follows: 70%: 30% (70%: Titanium Alloy + 30%: Silicon Carbide) and: 60%: 40% (60%: Titanium Alloy + 40%: Silicon Carbide)

Table 1. Table of materials used on MMC by SHS processed.

Materials	Role of function	Size
Titanium (Ti)	Matrix	80 µm
Silicon Carbide (SiC)	Reinforcement	360 µm
Alumina (Al_2O_3)	Reinforcement	360 µm
Stearad acid (CH_3COOH)	Lubricating fluid	250 gr
Liquid alcohol	Lubricating fluid	0.5 l
Ethanol	Ejector	0.5 l

2.2 Dies preparation and SHS Processed

The weighing process is completed by following the preparation of the SHS process dies for the powder which will be carried out the compacting process. The stages of dies preparation and the process are as follows: cleaning dies by gas and a compressor, so that the powder to be packed is not contaminated with other elements. Furthermore, the measurement of the frame precision on dies is accompanied by a marking on the ejector so that at the time of compacting the dies, does not occur slips so that the sample is easily removed. After that, coating the dies cavity with a stearid acid type lubricant so that the compacting and pressing process can be done easily and there are no obstacles:

2.3 The compacting process of SHS

The experimental device is presented in Figure 1. Also, the sample undergoing SHS combustion has been illustrated in the Figure 2.

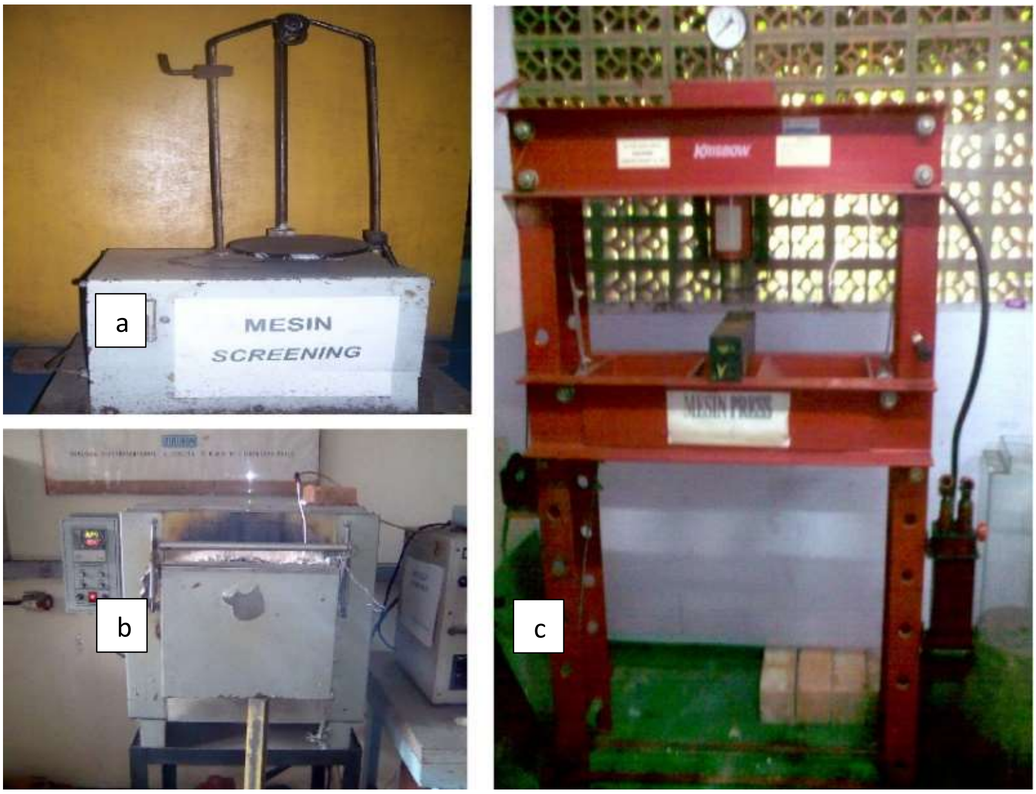

Figure 1. Equipment device of self-propagating high-temperature synthesis (SHS)
a) Screening Machine (Sifting) b) Muffle Furnace for SHS c) Press machine to compact sample

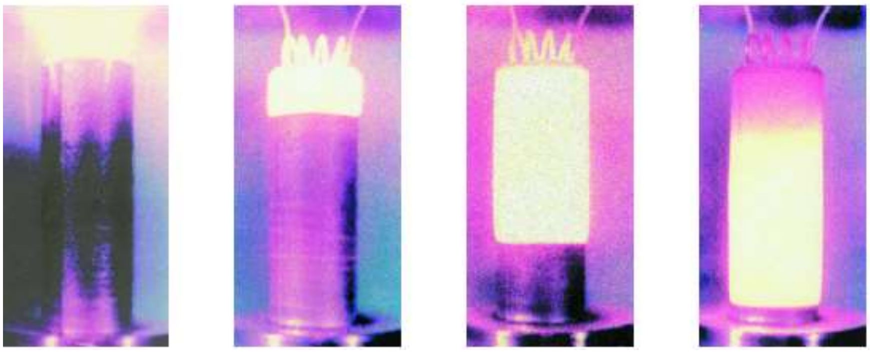

Figure 2. Exothermic reaction process in SHS samples [9]

The SHS compacting process has been carried out in the stages according to the amount of compacting force applied. The SHS process was assisted by constant pressure. The stages of making Ti/SiC based composites by SHS were as follows: Initially, each powder was prepared, both Ti/SiC. Furthermore, the powder was put into a vessel / container that will be put into the vessel so that the powder can be adjusted according to its volume fraction. Titanium and silicon carbide alloy powder that has been mixed into the dies which in the dies cavities has been coated with stearid acid as a dies lubricant to the pressure rod.

The SHS and compacting processes are measured based on the force required to unify the powder material which is carried out in stages and adjusted to the compaction holding time. Pressing the powder raw material on the compacting machine and pressing is done based on the forces required. Then sintering using muffle furnace programming, at temperatures of 900, 1000, and 1100^{0}C on the sample results of compaction and holding time for 1 hour. After reaching the desired temperature and holding time for 1 hour, the sample was removed from the muffle furnace. Combustion and pressing follow the stages of the process, after heating the SHS, the pressing stage was continued.

3. RESULTS AND DISCUSSIONS

The experimental results have been focused in Ti/SiC based composites, porosity measurement data, hardness values and metallographic observations. SHS temperature process was used which takes place at a temperature of 900-1100^{0}C. Table 1 depicts various characteristics of the tests.

Several test results like density have been affected by the SHS temperature. The density decreases with increasing SHS operating temperatures. The greater of temperature causes the density of powder particles to be formed where compacted titanium powder is able to fill the pores between the silicon carbide particles. Optimal density results with a value of 4,46 gr/cm3 have been achieved at sintering temperature 1100^{0}C where the volume fraction were 60: 40%. Furthermore the smallest density value correspond to 4,23 gr/cm3 at temperature 1000^{0}C where the volume fraction were 60: 40%.

The Porosity is a gas or air trapped in the microstructure of the materials where porosity affects the mechanical properties of Ti/SiC composites. Porosity in the structures that can influence in mechanical properties is caused by shrinkage of the captured gas due to differences in pressure and temperature [11]. Due to transition temperature of the material we have seen shrinkages during a compression process [12]. Afterward the results have seen a reduction in volume by using compression process. Our previous research work at [13-15] have shown in the microstructure of the materials the gas-induced porosity results due to changes in temperature. Also, the porosity test results by increasing SHS sintering temperature have seen increased value of the porosity. The minimum porosity with the value 2.36% corresponds to the temperature 900^{0}C at a volume fraction of 70:30%. The largest porosity with the value 5.85% corresponds to the 1000^{0}C at a volume fraction of 60:40%. The Table 2 depicts physical and mechanical properties of Ti/SiC based composites.

Table 2. Physical and mechanical properties of the Ti/SiC based composites

Volume Fraction (Vf: %)	Temperature (^{0}C)	Initial Sample Weight (gr)	Heavy after compacting (gr)	Weight after Sintering (gr)	Porosity (%)	Hardness (HRB)
70%:30%	900	4,759	4,505	5,292	2,36	91
						93
						93
	1000	4,683	4,526	5,488	3,28	x
	1100	4,408	4,307	5,208	4,1	16
						27
						14
60%:40%	900	4,644	4,427	5,209	4,,1	47
						56
						60
	1000	4,605	4,246	5,123	5,85	33
						65
						51
	1100	4,548	4,461	5,398	4,33	62
						57
						63

x – Sample was not bonded and has been destroyed through SHS process

The hardness values presented in Table 2, depict the resistance of the material to plastic deformation due to loading of measurement. The optimum hardness occurs at low sintering temperatures. The hardness of the material is influenced by compacting and porosity factors. At a volume fraction of 70: 30% with a maximum SHS sintering temperature reaching 1000^{0}C, it tends to decrease. The highest hardness was achieved at a volume fraction of 70: 30% with a sintering temperature of 900^{0}C, namely 92 HRB. This is because of Ti forms a smooth, protective layer on its surface. This prevents oxidation and corrosion inward. Based on field experiments when Ti heating reaches 1000^{0}C, the phenomenon that occurs is the occurrence of TiO, Ti2O and TiO2 skin layers, while the hydrogen formed from water vapour in the air is absorbed by Ti. Furthermore O and N, are also absorbed by Ti, which gives rise to hard titanium. Therefore Ti becomes brittle when heated at or above 700^{0}C. Based on theoretical basis [16] Titanium is very susceptible to oxidation in the air environment.

Optical microscope with magnification of 200x has been used to investigate metallographic analyses of Ti/SiC grains. Figure 3 depict the distribution of reinforced silicon carbide which is spread over the Ti matrix region. In the experiment, the greater the temperature of the given SHS, the more evenly the SiC distribution is spread over the matrix area, so that the SiC powder will fill the pores of the Ti powder. The maximum temperature can influence in a reduction of the SiC distribution. The transformation phase point of titanium has been realized at temperature 882^{0}C from α Ti (hcp) β Ti (bcc) and α condition was at low temperature which allows the formation of porosity by causing the decrease of the mechanical properties [4, 16]. The forming mechanism of the bond between Ti as a matrix and SiC as a reinforcement has been done by compacting process. Each powder moves with each other and a green compact occurs when the sintering temperature reaches 882^{0}C from α Ti (hcp) β Ti (bcc). Afterward we have seen the interlocking between the matrix and reinforce occurs where the bond produces a uniform powder distribution between each powder particle through the heating process by SHS.

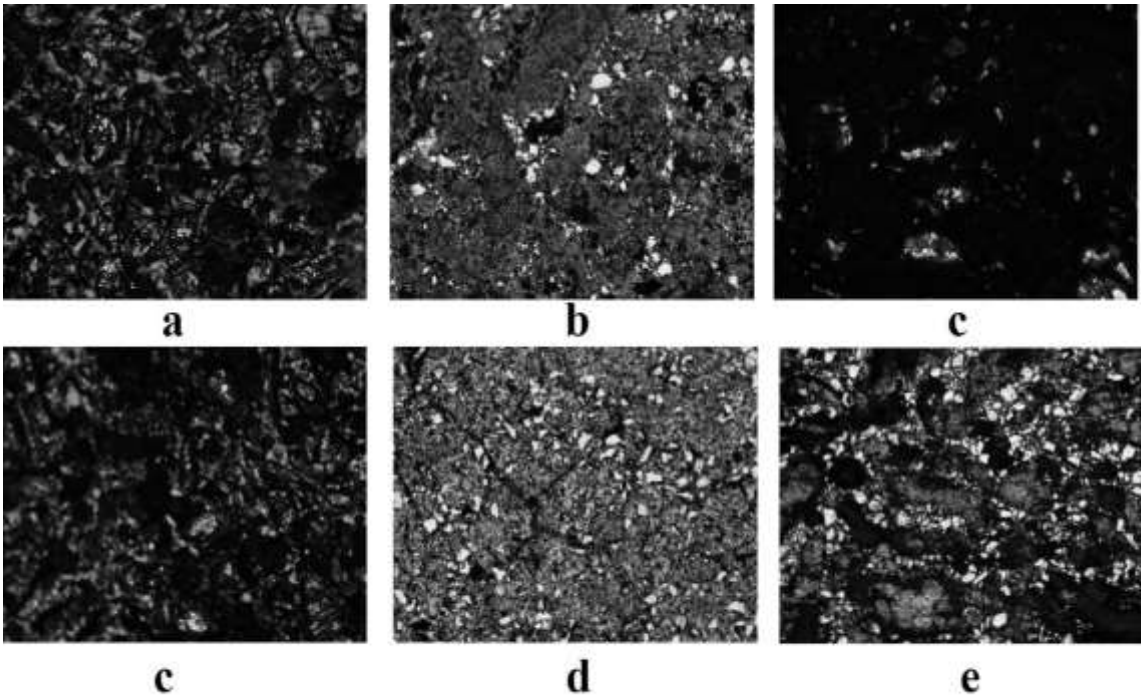

Figure 3. Distribution volume fraction of Ti/SiC: a) Vf: 70:30%, at: 900^{0}C b) Vf: 70:30%, at: 1000^{0}C c) Vf: 70:30%, at: 1100^{0}C d) Vf: 60:40%, at: 900^{0}C e) Vf: 60:40%, at: 1000^{0}C f) Vf: 60:40%, at: 1100^{0}C

4. CONCLUSION

In this paper we have described the fabrication of the Ti/SiC based composites by using SHS process. Our results have shown that by increasing SHS temperature, the porosity it has been decreased at the volume friction of 60:40 %. The minimum porosity with the value 2.36% corresponds to the temperature 900^{0}C at a volume fraction of 70: 30%.

The maximum hardness value was 92 HRB which it corresponds to the sintering temperature 900^{0}C at the volume fraction of 70: 30%. Furthermore, the lowest hardness value was 16 HRB which corresponds to the temperature of 1100^{0}C at the volume fraction of 60:40%.

Metallographic analysis has shown that by increasing the sintering temperature 882ºC from α Ti (hcp) to β Ti (bcc) the powders move with each other and occur to the green compact. Interlocking of the grains between the matrix and reinforcement has been realized through reinforcement phenomenon. It has been produced a uniform powder distribution between each powder particle. These results can influence in the improvement of mechanical properties.

ACKNOWLEDGMENT

The authors would like to thank Metallurgy Department of the Faculty of Engineering at Universitas Sultan Ageng Tirtayasa (UNTIRTA) for their support of this research work.

CONFLICT OF INTERESTS

The authors would like to confirm that there is no conflict of interests associated with this publication and there is no financial fund for this work that can affect the research outcomes.

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