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INFLUENCE OF CERAMIC PARTICLES ON THE MICROSTRUCTURE AND MECHANICAL PROPERTIES OF SAC305 LEAD-FREE SOLDERING MATERIAL

In this study, silicon carbide (SiC) reinforced lead-free solder (SAC305) was prepared by the powder metallurgy method. In this method SAC305 powder and SiC powder were milled, compressed and sintered to prepare composite solder. The composite solders were characterized by optical and scanning electron microscopy for the microstructural investigation and mechanical test. Addition of 1.5 wt. % and 2 wt. % ceramic reinforcement to the composite increased compressive strengths and microhardness up to 38% and 68% compared to those of the monolithic sample. In addition, the ceramic particles caused an up to 55% decrease in the wetting angle between the substrate and the composite solder and porosity was always increased with increase of SiC particles.

Keywords: composite solder, SiC particles, microstructure, wettability, microhardness

1. Introduction

High performance and miniaturization are important keys for the lead-free solders so the quality and reliability are important to develop high-performance lead-free solder alloy. Recent approaches in developing SAC305 solder and other solders alloys involve the addition of fourth alloying elements such as SiC, TiO_2, Al_2O_3, Fe_2NiO_4, and ZrO_2. These reinforcement materials are specified as potential materials that could improve the mechanical properties, electrical properties and microstructural stability through addition in to the conventional solders. The low cost, ease of production and higher hardness of SiC have main interest regarding its addition in to SAC305.

Tsao et al. [1] thoroughly investigated the microstructural and the mechanical properties of TiO_2 and Al_2O_3 nanoparticles reinforced SAC composite solder; the microhardness, ultimate tensile strength and yield strength of the composite solders were improved. Yu et al. found that the addition of rare earth metals in the SAC solders, the tensile strength, the wettability and elongation of the composite solders were enhanced [2,3]. The effect of SiC reinforcement on the microstructure and mechanical properties (microhardness) of SAC solder investigated by Liu [4]. The result showed that with and without the reinforcement of SiC particles, the microhardness of the composite solders was enhanced and grains of the composite solders were refined [5,6].

For improvement of mechanical performance, various reinforcing particles were established to be effective surface-active reagents and thus prepared composite solders. Attempts for reinforcing SiC particles into the Sn-3.0Ag-0.5Cu eutectic alloy were made first here by means of milling [7]. By other authors the effects of SiC additions on the lead-free composite solder microstructure, porosity, wettability and microhardness of the composite solder were also investigated [8,9].

Usually nanoparticles and micro particles have high specific area which is more than 150 m^2/g for silicon carbide particle [10,11]. When ceramic particles or reinforcements are mixed with a metallic powder or matrix, it is necessary to reach all the reinforcing particles on the surface of base material. Ball milling causes indentation of nanoparticles or micro particles into metal particles [12,13]. Therefore, reinforcement distribution in the matrix becomes more uniform, which is desired for metal matrix composites. Moreover, in this condition, enough metallic surfaces of particles are covered by the reinforcing particles.

In this paper we report our experimental work on the examination of influence of SiC ceramic particles on the microstructure and mechanical properties of SAC305 solder material.

2. Experimental

2.1. Materials

Lead-free solder powder and SiC particles were purchased from Cobar Europe B.V., Breda, Netherlands and SIKA TECH. Switzerland. In this study, the powder metallurgy route was used to fabricate composite.

In our experiments, lead-free (Sn-3.0Ag-0.5Cu) solder powder of size range 20-28 μm; silicon carbide (SiC) particu-

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lates (1-3 μm) were used. Varying weight percentages of SiC particulates were reinforced into the solder matrix to synthesize different systems of lead-free solder composites.

2.2. Preparation of SiC/SAC305

SiC reinforced composite lead-free solders were prepared via powder metallurgy route incorporating 0-3 wt. % of about 2 μm average SiC particles into Sn-3.0Ag-0.5Cu solder materials. The composite lead-free solders were simply referred to as SAC-XSiC, where X is the weight percentages of SiC. For lead-free solder composites, firstly, the lead-free solder powders and SiC particulates were pre-weighed and mixed homogeneously in a planetary ball milling.

Table 1 shows setting parameters of ball milling. First and second experiment did not give the satisfactory results because lack of homogeneous distribution of SiC, so milling parameters revised, and the third experiment settings provided satisfactory results.

TABLE 1

Milling parameters during milling

Materials	Powder size (μm) SAC/SiC	BPR	Balls size (mm)	Medium	Milling time (hour)	Rotational Speed (rpm)
Experiment-1						
SAC305/X wt. %SiC	29/2	20:1	10	Ethanol	3	200
Experiment-2						
SAC305/X wt. %SiC	29/2	10:1	3-10	Ethanol	3	200
Experiment-3						
SAC305/X wt. %SiC	29/2	10:1	3	Ethanol	1	200

Seven sample of SAC305-XSiC containing 0-3 wt. % of silicon carbide were prepared for further processing. The correct mixture of raw materials for each sample was milled for one hour in a planetary ball mill under an argon atmosphere using wear resistant hardened steel balls and bowl with a ball to powder ratio of 10:1. The rotation speed was 200 rpm for all samples and ethanol was employed as a medium [14].

Then, the ball milled samples of SAC305-XSiC lead-free solders were compacted at 200 MPa pressure in a cylindrical die of 15 mm inner diameter at ambient temperature. Lubrication oil was used as a lubricating agent in the die compaction to easy ejection and densification of the compacted samples. After that these samples were sintered in a tube furnace at 200°C for 3 h under an argon atmosphere.

3. Results and discussion

In this condition, the maximum metallic surface of particles are covered by the ceramic particles which help better particle connection and material consolidation in later processing stages.

In the experiment 1 and experiment 2 (Fig. 1a), the SAC305 and SiC were collected at some points and deformed as a flaky shape i.e. the homogeneous distribution did not show in the experiment 1 and experiment 2 (Fig. 1a). Fig. 1b (experiment 3) shows the homogeneous distribution of SAC305 and SiC particles because all the SiC particles are reached on the surface of SAC305. Fig. 1a and 1b are the SEM image of the powders SAC305 metallic particles and 0.5 wt. % SiC particles mixture of three-hour and one-hour ball milling. It proves that after one hour ball milling, SiC particles are uniformly distributed on the surface of metallic powder particles.

3.1. Microstructural investigation

Microstructural investigation was performed to study the effects of SiC ceramic particles on the microstructure of the SAC305 matrix. To prepare the samples of SAC305-XSiC com-

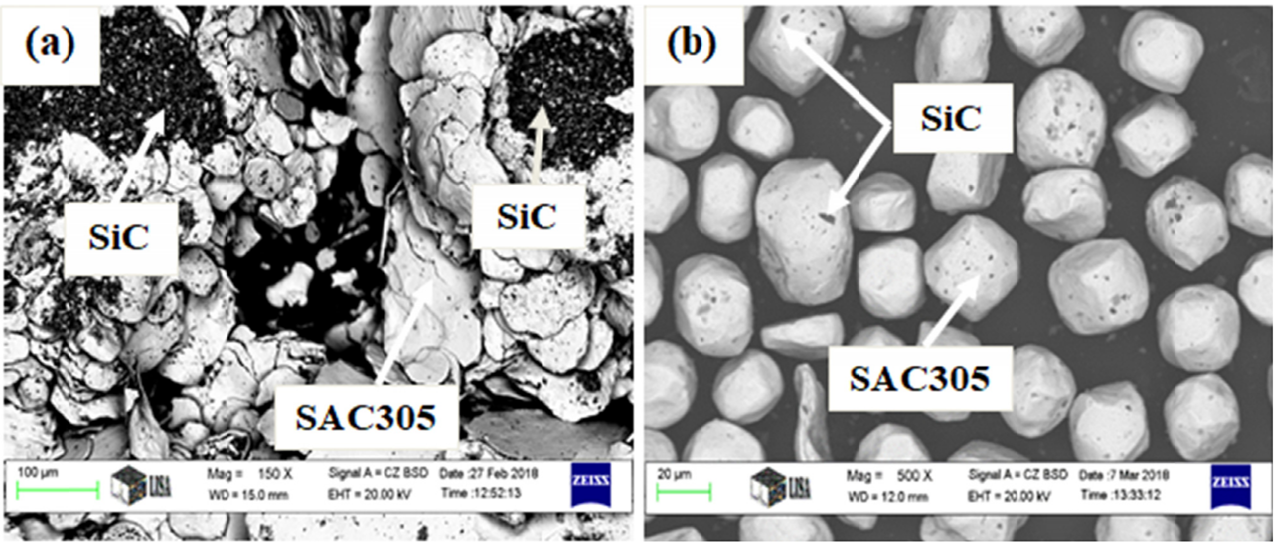

Fig. 1. SEM images of SAC305-0.5 wt. % SiC solders (a) 5 h milled and (b) 1 h milled

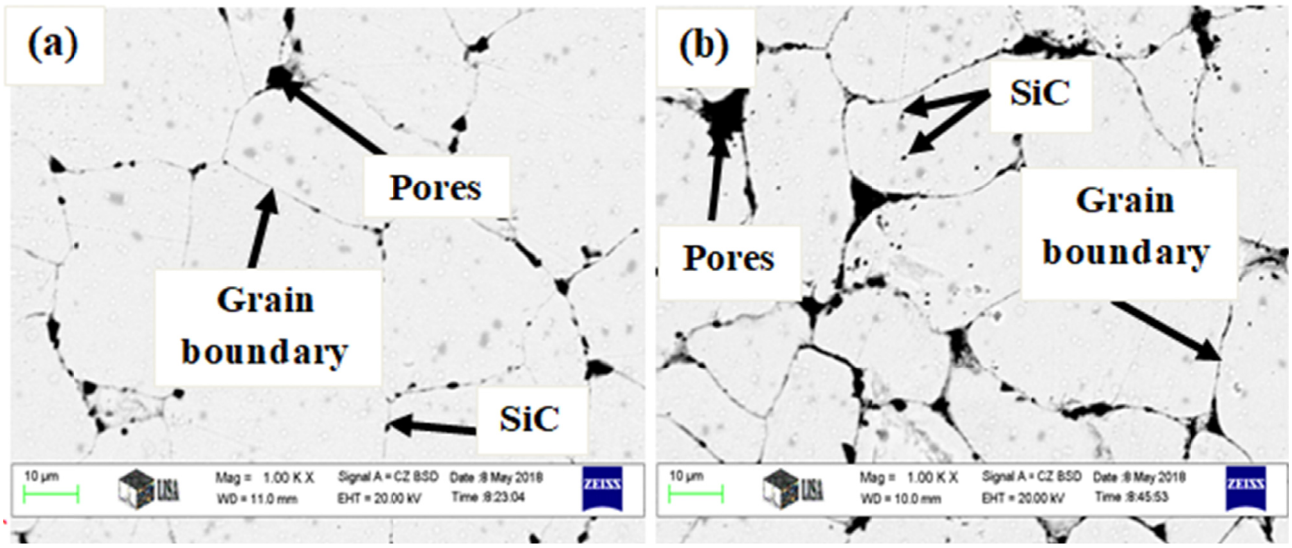

Fig. 2. SEM images of SAC305-wt. % SiC solders (a) 1% SiC (b) 2% SiC

posite solders, the common metallographic procedure polishing and grinding were used [15,16]. Then the samples were etched with a solution and the microstructure investigations were performed by metallographic microscope and SEM.

Fig. 2a and 2b shows the SEM images of 1% SiC and 2% SiC reinforced composites and in both composites, pores and grain boundaries are visible. The 0% SiC composite was a defect-free (no pores) while in 1% SiC and 2% SiC composite have some dark areas (pores) and grain boundaries are located. Some pores and agglomerates of reinforcement particles are visible between the matrix particles which did not join completely during sintering. The 0% SiC composites are perfect conditions and have the least of pores. In other composition (1% SiC, 2% SiC and 3% SiC) samples have more pores and thicker grain boundaries because of agglomeration of SiC.

From above microstructural studies, it is confirm that agglomeration of SiC particles on the surface of SAC305 and between matrix particles [11]. Fig. 2a and 2b are also confirmed that SiC particles are agglomerated at dark area which is likely pores which confirm that there are more pores around the agglomerates SiC.

3.2. Mechanical properties

Mechanical properties of monolithic and composite samples were also measured by microhardness, porosity, compression and wettability tests. Table 2 is a summary of the obtained properties. As can be seen, by adding SiC to SAC305 matrix, mechanical properties were increased. The highest mechanical properties were achieved at 1.5 wt. % SiC addition, where compressive strengths were increased by 14%, 34% and 38% respectively (Fig. 3). Microhardness was increased and maximum at 2 wt. % (Fig. 3).

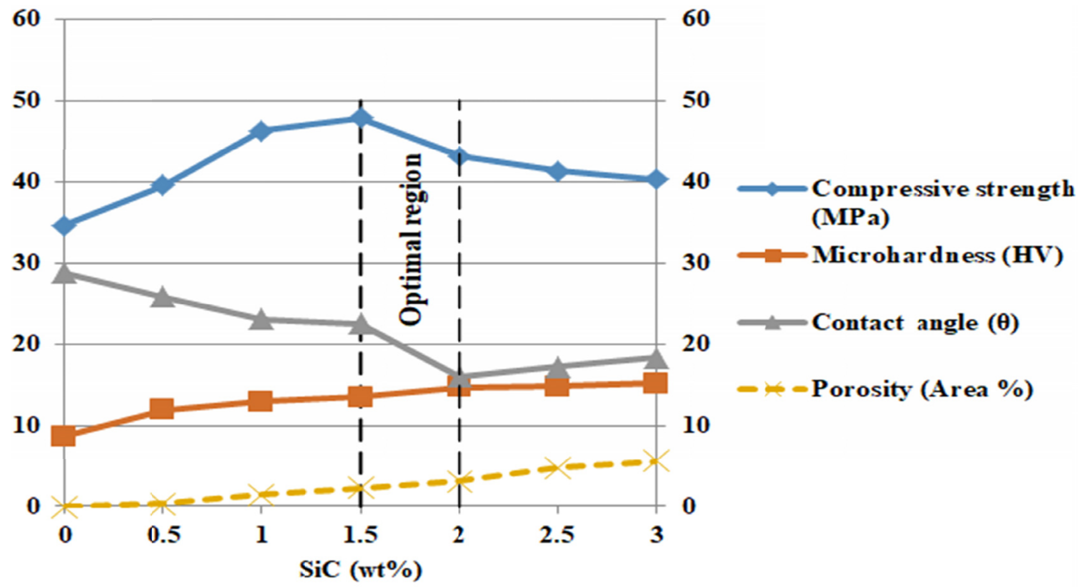

Fig. 3. Mechanical properties of SAC305 with different percentage of SiC

Mechanical properties increase could be due to increase in the number of ceramic particles resisting against plastic deformation. In addition, the coefficient of thermal expansion (CTE) difference between the matrix and particulate increases dislocation density and consequently mechanical properties [17]. Porosity was also investigated for all samples (0-3 wt. %) and porosity was very less at 0 wt. % SiC and maximum at 3 wt. % SiC content (Fig. 3).

TABLE 2

Mechanical properties of SAC305 and composite samples

SiC (%)	Microhardness (HV)	Porosity (%)	Compressive strength (MPa)	Contact angle (θ)
0	8.7	0.0	34.6	28.8
0.5	11.9	0.3	39.5	25.8
1	12.9	1.4	46.3	23.0
1.5	13.5	2.3	47.9	22.5
2	14.7	3.1	43.1	16.0
2.5	14.8	4.8	41.3	17.2
3	15.2	5.6	40.3	18.3

3.3. Wettability

Good wetting of substrate is important for lead-free solders. Copper is a good substrate for the lead-free solders because during solidification, it reacts with solder and form inter-metallic compounds.

When reinforcing particles are mixed to a lead-free solder, surface energy of the molten solder and reactions between substrate and solder are affected. Also if reinforcing particles segregate in triple point, they can affect balance of forces and reduce energy of the triple point [17].

Fig. 3 Shows the contact angle of SAC305 at different SiC content of the solder and it is evident that wetting angle decreases when SiC content increase, and consequently a better joint between the solder and the substrate is expected. The decrease of wetting angle is around 55% for addition of 2% SiC but after 2% SiC, the contact angles are start to decrease .

4. Conclusions

In this work, the influence of SiC particles addition on the microstructure and mechanical properties of SAC305 solder alloys was investigated. The major results are:

1. SAC305-Xwt. % SiC lead free composite solder could be successfully synthesized by powder metallurgy route.
2. SiC could effectively improve mechanical properties and wetting angle of Sn-3.0Ag-0.5Cu lead free solder.
3. Addition of 1.5% SiC and 2% SiC particles result optimum mechanical properties: maximal value of compressive strength and microhardness.
4. Addition of 2.5% and 3% SiC particles caused a drop in the mechanical properties such as and compressive strength and microhardness. Microstructural observations confirmed that development of porosity and agglomeration of SiC particles decreases the mechanical properties.
5. Wetting angle of copper substrate by the composite solder decreased around 55% for the optimum sample.

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