Materials Science Forum *Online: 2013-11-15*
ISSN: 1662-9752, Vols. 773-774, pp 226-233
doi:10.4028/www.scientific.net/MSF.773-774.226

Influence of Filler Amount and Content on the Mechanical Performance of Joints Bonded with Metal Powder Filled Adhesive

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Keywords: Adhesive, Metal powders, Lap shear strength.

Abstract. The objective of this study is to investigate the surface roughness that effect the capability of adhesive with adding aluminium powder and 63/37 Sn-Pb soft solder powder to the epoxy to increase the mechanical strength of joints. The adhesive strength of the joints was determined by utilizing the single-lap shear test. As seen from the experiments, the surface roughness has an important effect on the strength of adhesive bonded joints. Experimental results show that joints prepared by adhesive which was modified, adding in the amount of 5 wt% 63/37 Sn-Pb powder have more mechanical strength than joints compared to one which is prepared by adding aluminium powder with different ratios as 5, 25,50 wt%.

Introduction

Structural adhesive is an engineering material and adhesive bonding technique is well accepted part of production engineering. Today, adhesive bondings are being used extensively in aviation, aerospace and automative industries.

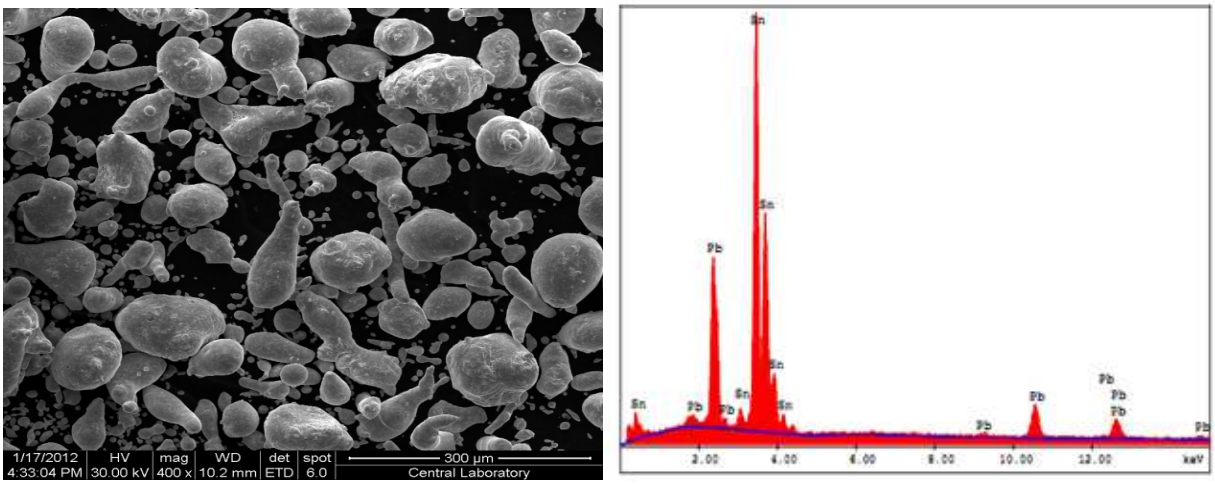
It is important that loads should be carried properly in adhesive bonding. As a course of their nature, adhesive materials' characteristic, working capability and strength are limited. Bonding strength of joints being subjected to specified load is related with a lot of factors. Generally, strength of adhesive bonding is related with size, thichness, geometry, elasticity modules, and bonding length of bonded parts, surface cleanliness of bonding area, bonding being sustained conditions, adhesive material and care that taken at adhesive bonding process. Furthermore, also surface roughness of bonded parts effects bonding strength. When studies[1,2,3] are examined, it is understood that surface roughness value can differ with the bonded materials and can be handled at a specified optimum value. However, the magnitude of the influence has not yet been clarified because of the complexity of the phenomena. Epoxy is a thermosetting material, which is very difficult to rework since it does not melt when reheated. In industrial applications, some filling materials are used with different proportions to increase the thermal conductivity of epoxy adhesives. Filler type, size, shape and volume fraction determine the adhesive thermal conductance. Conductive adhesives developed from this type of polymer exhibit higher shear strength than those from thermoplastic. An electrically conductive adhesive is made of metallic filler particles loaded in the matrix of a polymer material. Soft solder powder is a filling material used in conductive adhesive to supply the electrical conductivity [4]. Alumina powder is one of the commonly used fillers for improving the thermal conductivity of adhesives, in particular insulation adhesives. In adhesive bonding, adding filling material into the adhesive is frequently used to increase the electrical and thermal conductivity. However, while the improvement on thermal properties of adhesives by addition of metal fillers is obvious their influence on the mechanical properties of the adhesive joints ar not clear [5]. The studies which done by adding nano and micron particles into the adhesive are summarized below.

Kilik and Davies [6]; made a series of mechanical tests to evaluate mechanical properties of epoxy material that 50, 75, and 100 μm aluminium and copper powders added into. They prove that powder proportion and type lead to some mechanical property changes. Evidences show that although adding powder into adhesive does not have an advantage on tensile strength and impact energy, it has good results on semi-static tests as shear and t-peeling. Wang and others [7] searched performance and preparing methods of high temperature adhesive being used in graphite materials in their papers. In their study, high temperature adhesive was prepared by adding some ceramic filling material into phenol formaldehyde (PF) resin as matrix to change adhesive performance. When shear strength of bonded samples being processed at different temperature is investigated, it is proved that while bonding strength of samples which bonded with pure PF resin decrease with temperature, it was seen that bonding properties of samples which bonded with modified PF resin with ceramic filling material is high. In their studies, Zhai and et al. [8] added nano sized powders as Al_2O_3, $CaCO_3$ and SiO_2 into epoxy to improve the bonding strength. The bonded made by modified adhesive with these powders has more bonding strength than non-filled adhesive. Especially, the bonding strength was increased from 3.8MPa to 18.4MPa by adding 2 wt% nano-Al_2O_3. Kahraman and et al. [5] searched effects of adhesive thickness and the amount of filler on mechanical performance at joints which bonded with epoxy material filled by aluminium powder. Bonding strength was obtained from single lap shear tests. While some joints were formed by pure adhesive, others were being formed by modified adhesive with different amounts (10, 25 and 50 wt%)of aluminium powders. Experimental results has showed that bonding strength increases by adding different amount of powders into adhesive. Also, after 50 wt% powder added into the epoxy, they have expressed that bonding strength still continues. The tensile test results of Zhao and Li [9] showed that nano-Al_2O_3 powders being added into epoxy were improve matrix strength. Epoxy's tensile strength were increased depending on amount of added nano-Al_2O_3 powders.
May and et al. [10] investigated bonding strength of pure epoxy and modified epoxy prepared with sol-jel method. The powders added into sol-gel were multiwall carbon nanotubes (MWCNTs) and γ-Al_2O nanoparticles. In comparison to additive-free epoxy, modified epoxy had an important increase in bonding lap shear strength. Results show that bonding performance between layer surfaces was improved by joining of inorganic nano particules in the epoxy/sol-gel adhesive as an amount of specified ratio. Bahattab and et al.[11] added nano-SiO_2 particules into polyurethane (PU) adhesive with different sizes (20, 50 and 100 nm). The stainless steel/polyurethane joints bonded with this modified adhesive had more single lap shear strength in comparison to additive-free adhesive. So far, it has not been encountered any researches that investigate the soft solder powder effects on mechanical strength in the adhesive. Filler materials in the adhesives are mostly copper, aluminium, short carbon fibers, nano-TiO_2, nano-Si_3N_4 and nano-ZnO. In this study, different amounts of 63/37 Sn-Pb solder and aluminium powders added into epoxy as additive fillers. In experiments done with single lap joints, the effects of the surface roughness factor at joints surface and the amount and type of powders added into adhesive on mechanical strengths are searched.

Experimental

Material and Method

In experiments, Permabond ESP110 named adhesive was used. Permabond ESP110 is an epoxy which is single component and being cured with heat. Filler materials are irregular 44~100 μm sized soft solder powder and spherical formed aluminium powder which is 60 μm in diameter. Solder powder's melting point was measured as 181 ºC with SETARAM LABSYS DSC measuring device at TUBITAK Marmara Research Center (Turkey). SEM picture and EDX analysis result of 63/37 Sn-Pb alloy can be seen at Fig. 1. SEM pictures were taken by Quanta 400 Field Emission high definition (1,2 nm) Scanning Electron Microscope equipped with an energy dispersive X-ray analyzer (EDAX).



(a) (b)

Fig. 1 (a) SEM picture and (b) EDX analysis of solder alloy

Erdemir 6112 (St 12) steel plate had been chosen as an experimental material. In the selection of material widely usage of steel plate in the industry had been taken in account. Experimental material is widely used in home appliance and automative industry. Steel samples were prepared according to standart [12]. Samples shapes are shown in Fig. 2. The chemical composition and mechanical properties of steel plate are given at Table 1 and Table 2, respectively. Also in Fig. 3, tensile diagram of steel can be seen.

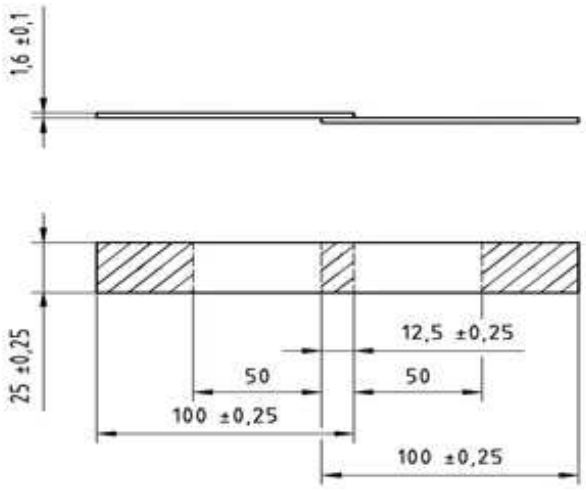


Fig. 2 Configuration and dimensions of lap shear bonded specimens

Table 1. Chemical composition of steel

Chemical composition wt %			
Carbon (C)	Phosphore (P)	Sulfur (S)	Manganese (Mn)
0.12	0.045	0.045	0.60

Table 2. Mechanical properties of steel

Yielding (kg/mm^2)	Tensile strength (kg/mm^2)	Elongation (%)
23.98	34.8	30.79

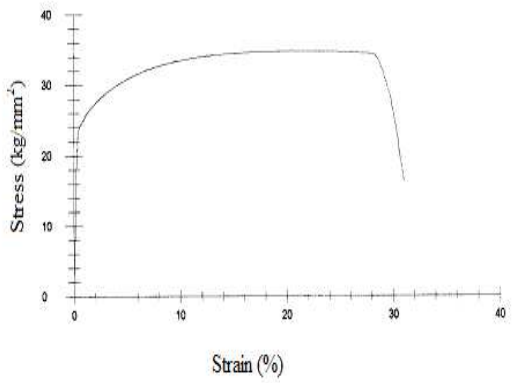


Fig. 3 The stress–strain curve of steel

The surface roughness of joints is one of the most important parameters that effect the bonding strength. In this study, mechanical abrasion (emery papers) was chosen to prepare joints surfaces to research effects of that parameter on strength. The bonding region of samples were abraded by 3M Diaped (diamond abrasive), 60, 150, 600 SiC emery. The abraded surface was cleaned with acetone and washed with distillate water as in Kahraman[5] and others' [13] studies. After drying with hot air for adhesion prosess, the samples' surface roughness were measured. The surface roughness measurements were made with Mitotoyo Surfest 301 measuring equipment according to standarts [14]. Adhesive material and filler powders were mixed in a plastic plate and then applied on the joint surfaces with the help of spatula. The mechanical pressure (about 50kPa) was applied on the samples' adhesion joints with the help of two metallic paper clips. That type of pressing method is being used by some researchers [15,16,17]. All bonding processes were done at the 180 °C furnace temperature. At this temperature, 63/37 Sn-Pb solder alloy does not start to melting and powder in the adhesive is still kept as powder. The structure was protected to search and compare solder and aluminium powder's effects on adhesion joints mutually. Adhesion joints were cured by using Heraeus Oven Model T 5042 EK drying furnace.

Results and Discussions

Before adhesive bonding with Permabond ESP 110, sample's surface roughness was measured from over lapped region (bonding surface) are given on Table 3. Seven couples of adhesive bonded samples with Permabond ESP110 were prepared according to TS EN 1465 [12] standard and then their shear tensile strengths were measured. 10-ton Zwick Z100 tensile measuring equipment was used for tensile tests. Tensile speed was 1mm/min and its speed was constant. The results of steel-steel plate bonded with non-filled adhesive give us information about adhesion strengths of joints. From Table 4, it is seen that the strength of samples prepared using 3M diaped are higher than other samples. It is proved with tests that joints has more shear strength according to the surface roughness value of 0,53μm at adhesive bonding joints obtained with 3M Diaped emery. For steel-steel adhesive bonding joints, the optimum surface roughness value has been found. It was decided that for the surface preparation of samples bonded with metallic filler added adhesive was made by 3M Diaped emery.

Table 3. Surface roughness values of samples- for Permabond ESP110

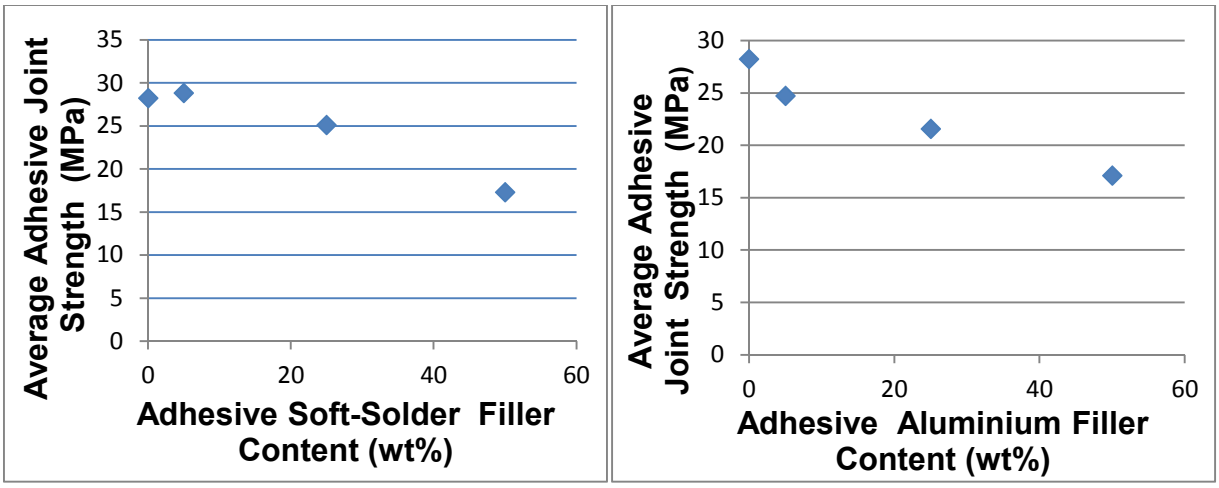
Avarage surface roughness Ra (µm)			
60 SiC emery	150 SiC emery	3M Diaped emery	600 SiC emery
0.90	0.70	0.53	0.21

Table 4. Average shear strength (MPa)-for Permabond ESP110

Avarage shear strength (MPa)			
60 SiC emery	150 SiC emery	3M Diaped emery	600 SiC emery
26.53	27.60	28.20	22.61

The surface roughness value is 0,21 µm at the surface which was prepared with 600 SiC emery. The mechanical strength of that samples gave worst value than joints abrasived with other emeries. It could be caused by the removal of mechanical locked due to insufficient adhesive penetration on flat surfaces. If the surface roughness increase more than enough, strength will decrease again. On rough surface, adhesive can not spread and ineffecient adhesion wetting will occur [2]. These facts and comments are compatible with literature [18]. Thus, although the strength values of joints prepared by 60 and 150 SiC emery are nearly equal, strength value of joint prepared by 3M Diaped gives better results.

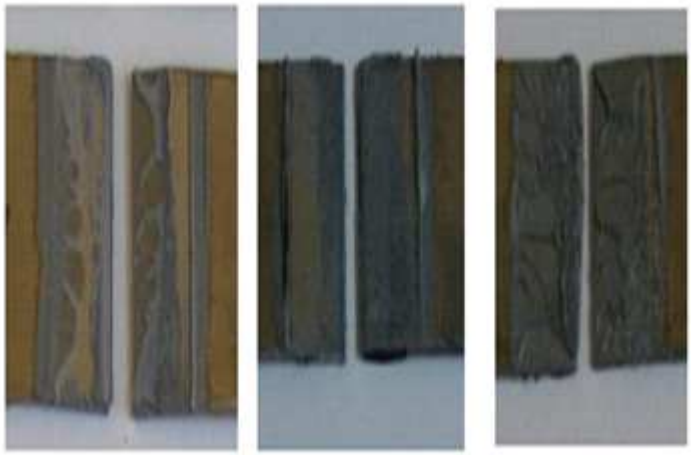
The shear strenghts of joints which were prepared by soft solder and aluminium powder (5, 25, 50 wt%) added into adhesive seperately was measured. For each amount of percent ratios, 5 samples were prepared and graphics were obtained by taken average of these 5 samples' shear strength values.



(a) (b)

Fig. 4 Effect of powder additions on the lap shear strength of the adhesive joints; a) soldering powder, and b) aluminium powder

It can be seen from the Fig. 4 (a) and (b) that mechanical strength of joint decreases when the amount of powders in the adhesive exceeded 5 wt%. It is known that mechanical strength decreases while the powder ratio in the adhesive increases [6]. Nevertheless, the joints prepared with solder powder has more mechanical strength than one prepared with aluminium powder. Differences in shear tensile between solder and aluminium powders probably result from powder forms (shapes). Aluminium powder is in spherical form. Hence, powder surface easily seperated from adhesive at tensile shear tests. It is conceivable that non-uniformed solder powder cause joint mechanical strength to increase due to clamping with adhesive and delay of seperation from adhesive. The rupture surfaces of adhesive bonded lapped joints prepared with 3M diaped are given at Fig. 5.



(a) (b) (c)

Fig. 5 Surface of breaking the joint a) Permabond ESP110, b) Permabond ESP110 filled 5 wt% solder powder, c) Permabond ESP110 filled 50 wt% solder powder

Adhesive bonded joints generally are faced with two types of damage models (adhesion and cohesion damages) [19]. Being adhesive at two surfaces after rupture process indicates that there is a cohesion damage. Rupture which is apparent separation of adhesive and plate surface is called as adhesion damaged. In Fig. 5 (a) and (b) it is seen mixed interface/cohesion fracture failure at rupture surfaces. Also in Fig. 5 (c) it is seen a cohesion failure at joint which has 50 wt% solder powder filler ratio.

Remarks

The melting temperature of powders added into adhesives is higher than adhesive cure temperature. In the future, it is foreseen that new hybrid joints can be obtained using nano-soft solder powder and adhesive (due to melting temperatures decreasing as nearby the adhesive cure temperature). Specially, researches [20,21] about production of nano-solder powder which is a new study area show that it will become interesting area.

Conclusions

Results from this study given below.

- The surface roughness of surfaces that prepared with different emery effects the mechanical strength on adhesive bonded joints. The joints prepared with 600 SiC emery give lowest shear-tensile value.

- The type and amount of powder which gives the greatest improvements vary according to the mechanical property. 63/37 solder powder added adhesive bonded joints has more strength than aliminium powder added ones.
- The strength decreases on the joints which prepared with 50 wt% amount of filler materials for both powders (solder and aliminium). Also, addition of these amounts of both powders made same effects on the strength of joints.
- The experimental results show that solder powder can be used as an alternative filler material within the powders which are added into epoxy.

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