

# Shear Strength of the Mixed Adhesive Joint Silyl Modified Polymer-Epoxy in Single Lap Joint Aluminum

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## ABSTRACT

*Shear strength of mixed adhesive joints (MAJ) silyl modified polymer (SMP)–epoxy (EP) in a single lap joint (SLJ) aluminum to aluminum has been investigated. Single lap joint specimens were made according to ASTM D-1002 standard. Three levels of mixed adhesive thickness of 0.2; 0.4; and 0.6 mm were used while the variations of mixed adhesive composition were 100%EP, 75%SMP:25%EP, 50%SMP:50%EP, 25%SMP:75%EP, 100%SMP. Sandpapering grid of 150 and acetone cleaning was performed on Aluminum surface. The pressure of 0.1 Mpa and post-curing of 100°C for 100 minutes were subjected on the mixed adhesive joint specimens. Shear tests and failure surface investigations were conducted to analyze the strength of the mixed adhesive joints. The addition of silyl modified polymer to epoxy decreases the shear strength and the shear modulus but increases the elongation of the mixed adhesive joints. The mixed-adhesive joint of 25%SMP:75%EP has the highest shear strength, even it is higher than that of the adhesive joint of 100%EP. There is no significant effect of adhesive thickness on the joint properties in the range from 0.2 mm to 0.6 mm.*

**Keywords:** Mixed Adhesive Joint, Silyl-Modified Polymer, Epoxy, Adhesive Thickness, Aluminum

## Introduction

Adhesives are widely used in industrial applications, such as airline [1], automotive [2], and marine industries [3]. The adhesive has function as a natural barrier at two different material metal joint, so that corrosion resistance increases [2]. The advantages of using adhesive joint types are light weight structure, low manufacturing costs, and repairable damage [4]. There are several types of adhesive joining process; one of them is a single lap joint (SLJ) [5]. Adhesive joint for a metal plate or composite material is the most common because it is simple and efficient in the process of making SLJ [6]. The joint strength can be influenced by many factors such as type of adhesive [7], type of adherend, overlap length and thickness of bond line [6]. Epoxy is one of thermoset polymer adhesive that widely used in composite materials, because of excellent properties, including good stable, chemical resistance, stiffness and low cost [9]. However, the scope of use epoxy is limited due to the brittleness with poor strength and toughness [10]. Epoxy is not suitable for a flexible material as it will crack if the material is deformed. Post curing is usually used to improve the mechanical properties of epoxy-hardener due to the perfection of crosslink inter-molecules [11]. In reverse, Silyl-modified polymer (SMP) is an adhesive with isocyanate-free, weak and high ductility. SMP adhesive has advantages such as solvent-free and PVC-free, very good resistance to UV, odorless, fast curing and permanent elastic at a temperature range from  $-40^{\circ}\text{C}$  to  $120^{\circ}\text{C}$ . SMP adhesive used in construction bonding metal or non-metal joint and seal on buses, trains, and trucks.

There are some methods to improve the properties of the adhesive joint. One of them is the addition of aluminum and nanosilica powder filler in specific content in adhesive [14,15]. Furthermore, the mixed adhesive between strong-brittle and the weak-ductile adhesive is alternatively used to improve mechanical properties of the individual adhesive joint [20]. For example, a brittle adhesive AV138 which has failure load 11,3 kN is mixed by ductile adhesive DP8005 which has failure load of 7,8 kN will fail at the load of 17,2 kN. The main advantage of mixed adhesive is adhesive strength become higher than the use of brittle adhesive or ductile adhesives only [7]. Moreover, mixed adhesives have differents rigidity in which joint strength of the mixed adhesive is higher than the strength of homogeneous adhesive in the bondline [12,13].

Adhesive joint improvement also can be performed by the surface treatment for coarsening and etching so that bonding between adherend and adhesive can occur and increase the strength and durability [4]. Adherend surface is coarsed by sandpaper and followed by chemical treatment such as chromic-sulfuric etch [15]. The chemical etching, sodium dichromate-sulfuric acid can

improve the adhesive joint strength more than caustic etching such as Tucker's reagent (TR) or solvent wiping [16].

Aluminum alloy 5083 has Magnesium as the main alloy element. Magnesium gives more advantages, such as good strength, good corrosion resistance when submerged in water, good formability and good weldability [8]. Based on these properties, it is widely applied in engineering structures. The main disadvantage of aluminum alloy is low strength and stiffness which is only about one-third those of the steel. It made aluminum deformed and deflected easily when the load is subjected to the aluminum structure. It will deteriorate when high modulus adhesive such as epoxy (EP) is used to join aluminum structures. It will generate the interfacial stresses along the bond line and let the adhesive crack. On the contrary, the use of low modulus adhesive such as a silyl modified polymer (SMP) will improve the flexibility of the adhesive joint, but it will decrease the joint strength [16]. This work proposed to mix the low and high modulus adhesive to join the aluminum alloy 5083 to improve the flexibility and strength of the adhesive joint simultaneously. Silyl-modified polymer (SMP) and epoxy (EP) adhesive were mixed in varying composition and used to make a single lap joint (SLJ). The mixed adhesive thickness were also evaluated. So, the aim of this work is to analyze the effects of composition and thickness of mixed adhesive joint silyl modified polymer-epoxy adhesive on the single lap shear strength of aluminum. It will be very important due to the limitation test data of mixed adhesive [16-20].

## **Experimental Procedure**

### **Materials**

Adherend was made of aluminum AA 5083 with a thickness of 3 mm. Two types of adhesive materials, Silyl Modified Polymer (SMP) and Epoxy were used. SMP adhesive was Simson ISR 70-05 produced by Bostik Inc., Netherlands. Epoxy (EP) adhesive was epoxy resin epichlorohydrin type of bisphenol-A (DGEBA) which has a viscosity of 13000 + 2000 MPa.s at 25<sup>0</sup>C and density of 1.17 ± 0.01 g/cm<sup>3</sup> at 25<sup>0</sup>C. The hardener was Polyaminoamide (PAA).

### **Joining processes and testing**

The aluminum plate was cut according to ASTM D1002 standard. Its surface was treated by sandpaper (SDP) with a grid of 150 and cleaned by using acetone. This research used two types of adhesives, Silyl Modified Polymer (SMP) and Epoxy (EP) to join the adherend. The variations of mixed adhesive composition were 100%EP, 75%SMP:25%EP, 50%SMP:50%EP, 25%SMP:75%EP, and 100%SMP, where variation composition was in

weight percent. Mixed adhesives SMP-EP were mixed by stirring for 5 minutes at 60 rpm.

Single Lap Joint (SLJ) specimens were made by gluing on the two surfaces of adherends. The configuration of SLJ specimens is shown in Figure 1. Three levels of mixed adhesive thickness of 0.2; 0.4; and 0.6 mm were used for each mixed adhesive. The combination of research parameters is shown in Tabel 1. During joining process, SLJ specimens were subjected the pressure of 0.1 MPa. The post-curing process at 100°C for 100 minutes was performed.

Shear strength tests of joined specimens were conducted by using Universal Testing Machine JTM UTS-210. Scanning Electron Microscope (SEM) TESCAN VEGA3 LM was used to investigate the failure surface of shear strength tests. The strength of the mixed adhesives materials was also evaluated to support the analysis of adhesive joint strength.

Table 1: Research parameters

No.	Adhesive composition	Adhesive thickness (mm)
1		0.2
2	100 % EP	0.4
3		0.6
4		0.2
5	75%SMP:25%EP	0.4
6		0.6
7		0.2
8	50%SMP:50%EP	0.4
9		0.6
10		0.2
11	25%SMP:75%EP	0.4
12		0.6
13		0.2
14	100% SMP	0.4
15		0.6

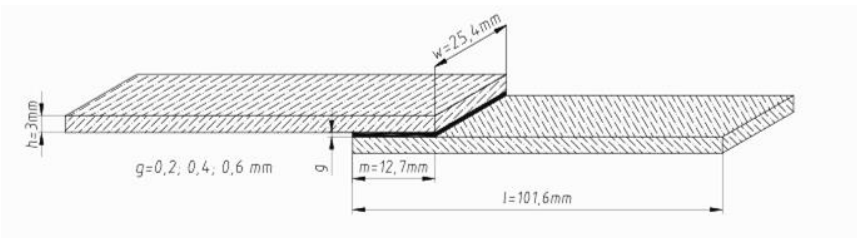


Figure 1: Single lap joint specimen (ASTM D1002)

## Results and Discussion

The surface roughness of the untreated adherend is low enough with Ra value of 0.84  $\mu\text{m}$ , while that of sandpapered of #150 grit is more rough with Ra value of 1.98  $\mu\text{m}$ . It shows that sandpapering treatment on the aluminum surface can increase the roughness more than 100% compare to without treatment surface. The appearance of the aluminum surface between untreatment and sandpapering treatment is shown in Figure 2. Surface treatment was not evaluated in this work. The use of sandpaper was aimed to clean the surface not to make the surface be rougher because the rough surface will decrease the shear strength of adhesive joint. The rougher surface has less wettability of adhesive materials which is in coherent with shear strength tests [21]

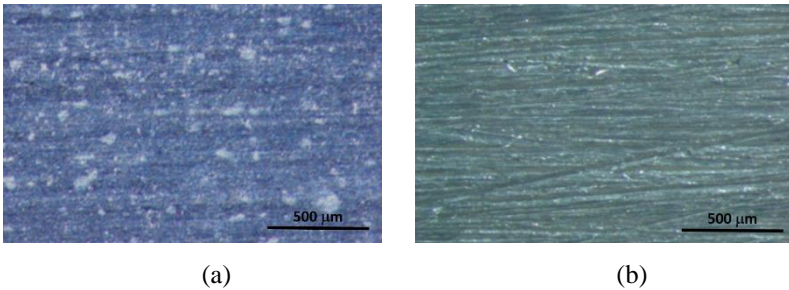


Figure 2: Surface appearance of (a) untreated and (b) sandpapered aluminum

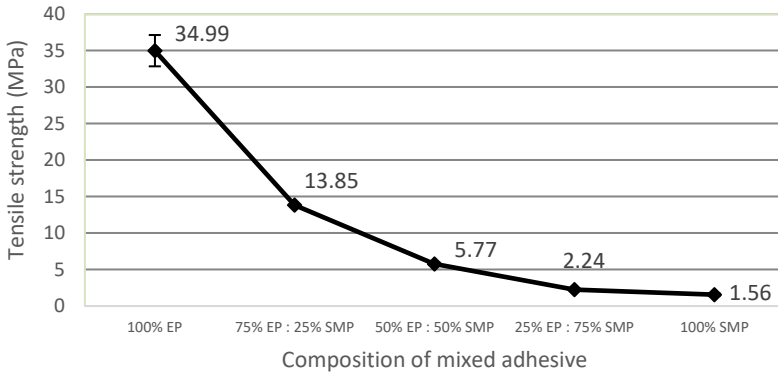


Figure 3: Tensile strength of adhesive and mixed adhesive materials

Epoxy (EP) adhesive has high strength and stiffness. Otherwise Silyl Modified Polymer (SMP) adhesive has low strength and stiffness [16]. Tensile test of both adhesive materials in this study indicated that the tensile

strength of epoxy (EP) was around 22 times of the SMP strength as shown in Figure 3. The addition of SMP on epoxy decreased the strength of EP-SMP adhesive mixture significantly. The tensile strength of the EP-SMP adhesive materials mixture compositions of 75%:25%, 50%:50%, 25%:75% were 40%, 16%, and 6% respectively lower than that of 100% EP.

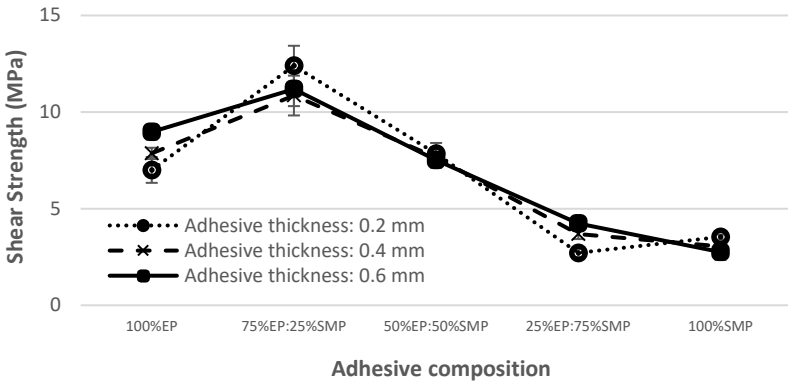


Figure 4: The shear strength of the mixed adhesive joint EP-SMP in single lap joint aluminum

Figure 4 shows the single lap adhesive joint strength of Aluminum AA5083 depending on the adhesive thickness and mixture composition. As previously predicted based on the strength of adhesive materials as seen in figure 3, the shear strength of 100% epoxy (EP) adhesive specimen is much higher than that of 100% Silyl Modified Polymer (SMP) adhesive specimen for all of the adhesive thickness levels. It is consistent with the nature of EP and SMP where EP is strong adhesive and SMP is weak adhesive. Typical failure mode was observed in both adhesive, whereas their failure characteristics were distinct. The specimens bonded with 100% EP exhibited an adhesion failure which is debonding between adhesive and aluminum as seen in Figure 5. The specimens with 100% SMP, however, demonstrated cohesion failure in which the adhesive experienced the shear failure as seen in Figure 6. This observation illustrates that the interfacial behavior has been controlled by the adhesion characteristics of SMP. The SMP adhesive is a soft adhesive where the shear deformation will dominate [22].

Figure 4 also shows that adhesive thickness range from 0.2 to 0.6 did not affect the adhesive joint strength significantly, and the effect of it depended on the composition of the adhesive mixture. When the adhesive was 100% epoxy, the thicker adhesive layer, the stronger adhesive joint. On the contrary, when the adhesive was 100% SMP, the thicker adhesive layer, the weaker adhesive joint. It due to the nature of both adhesives, epoxy is strong

and rigid, while SMP is weak and ductile. Also, the SMP adhesive data have less deviation than epoxy (EP) adhesive data. It is attributed to the fact that stable bonding formation of SMP adhesive can be achieved due to the viscosity before hardening of SMP adhesive is higher than that of epoxy adhesive [16]. From literatures review, it shows that there was no certain conclusion that explained the effect of the adhesive thickness on the strength of the adhesive joint. Some studies concluded that the thickness has a negative effect [23-28], others concluded that the thickness has a positive effect [29-30] and the others concluded that the thickness has no significant effect or the effect was depended on the type of adhesive and the overlap area [31-35]

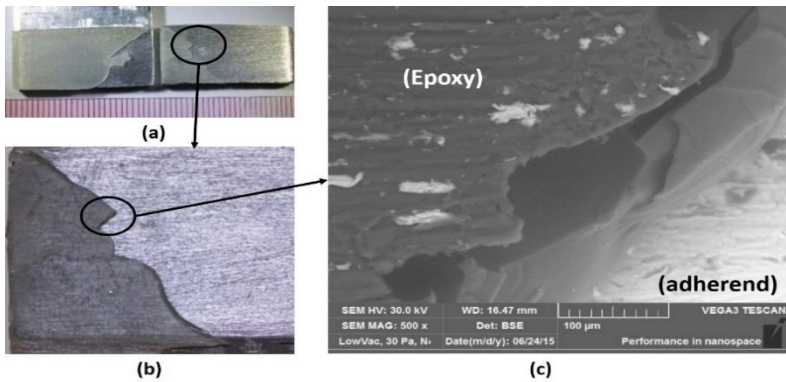


Figure 5: Failure morphology of adhesive joint with 100%EP: (a) macro scale, (b) detail of (a), (c) detail of (b).

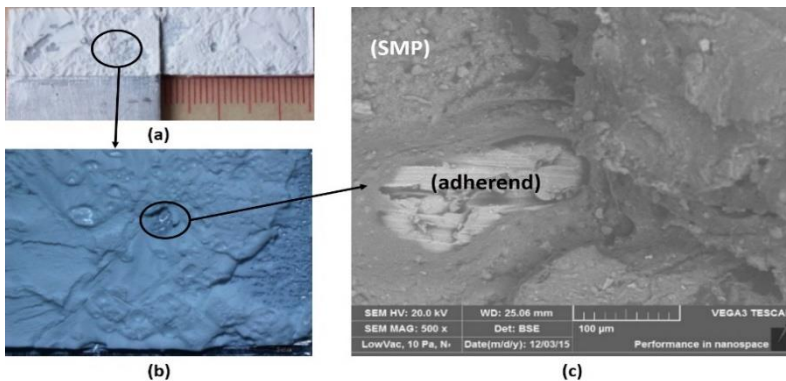


Figure 6: Failure morphology of adhesive joint with mixed adhesive 100%SMP: (a) macro scale, (b) detail of (a), (c) detail of (b).

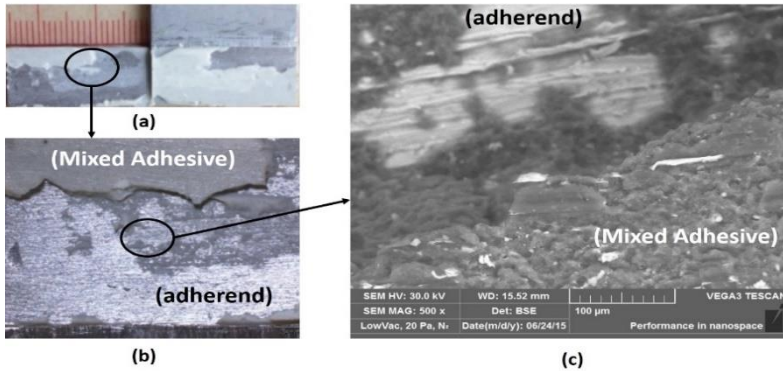


Figure 7: Failure morphology of adhesive joint with mixed adhesive 75%EP:25%SMP: (a) macro scale, (b) detail of (a), (c) detail of (b).

The strength of mixed-adhesive joints was between the strength of SMP and EP adhesive joints. The more of the SMP content in the mixed adhesive, the less of the shear strength of the mixed adhesive joint. However, the decreasing of shear strength due to increasing of the SMP content is not proportional. The shear strength of mixed adhesive joint with 25% SMP is the highest even it is higher than that of 100% EP. It is consistent with the previous research stated that the shear strength of mixed adhesive joint in the certain composition would be higher than that of adhesives alone [7]. In this work, it seems that the mixed adhesive of 75%EP:25%SMP is the most optimum composition. The combination of high cohesion strength and high adhesion strength is the main reason. The cohesion strength is maintained by 75% EP so the mixed adhesive is still strong enough, while the adhesion strength is controlled by 25% SMP so the mixed adhesive can adhere to the adherend strongly. The failure morphology of this joint as seen in Figure 7 shows this phenomenon. It exhibited a mixture of adhesion (debonding between adhesive and aluminum) and cohesion (within an adhesive layer). The strength of adhesion will increase as the increase of SMP content, but it will decrease the shear strength of the adhesive material. This phenomenon occurred on the mixed adhesive joint of 50%EP:50%SMP which had medium shear strength. The strength of adhesion between the adhesive material and adherend is excellent. When the load was subjected to joint, the interfacial adherend-adhesive will transmit it to adhesive well, and then adhesive will be subjected and failed by the shear force. In this condition, the adhesive joint will fail in cohesion failure mode as seen in Figure 8. The same phenomenon also occurred on the mixed adhesive joint of 25%EP:75%SMP. Even though interfacial strength is high, its strength is lower than that of the mixed adhesive joint of 50%EP:50%SMP due to its low shear strength. Figure 9 shows the failure morphology the mixed adhesive joint of 25%EP:75%SMP.



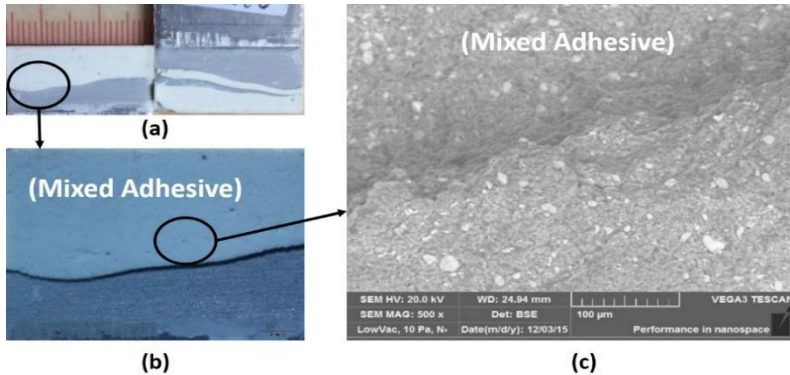


Figure 8: Failure morphology of adhesive joint with mixed adhesive 50%EP:50%SMP: (a) macro scale, (b) detail of (a), (c) detail of (b).

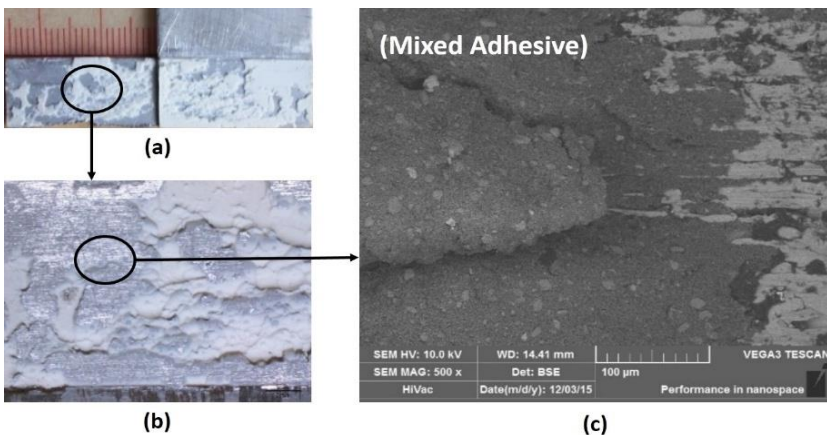


Figure 9: Failure morphology of adhesive joint with mixed adhesive 25%EP:75%SMP: (a) macro scale, (b) detail of (a), (c) detail of (b).

Besides shear strength, other parameters can be taken from shear test include elongation and shear modulus. Elongation exhibits the ductility of the adhesive joints while the shear modulus exhibits the stiffness of the adhesive joint. SMP is ductile while EP is brittle adhesive, so their content will control the ductility and stiffness of the mixed adhesive [16]. SMP content in mixed adhesive joints did not increase the elongation significantly. Epoxy has a significant effect on the elongation of the mixed adhesive joints and the shear modulus as well. Figure 10 shows that all levels epoxy content in the mixed adhesive make the joints has almost the same elongation which is about 10%.

Only free epoxy adhesive joints (100%SMP joints) had elongation more than 10%. In this case of 100%SMP joints, the thicker adhesive layer, the higher elongation of SMP joints. On the contrary, epoxy can maintain the stiffness of the mixed adhesive joints as seen in Figure 11. The levels epoxy content up to 50% in the mixed adhesive makes the joints has almost the same shear modulus which is about 100 MPa. It shows that no matter how much the epoxy content in the mixed adhesive will make it got brittle and stiff like the bulk of epoxy.

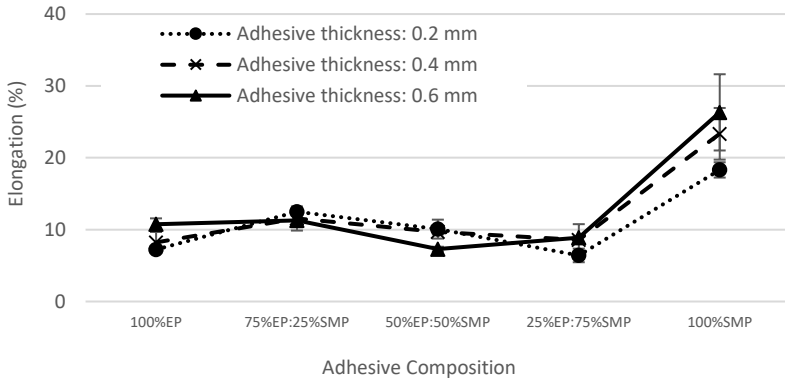


Figure 10: The elongation of the mixed adhesive joint EP-SMP in single lap joint aluminum

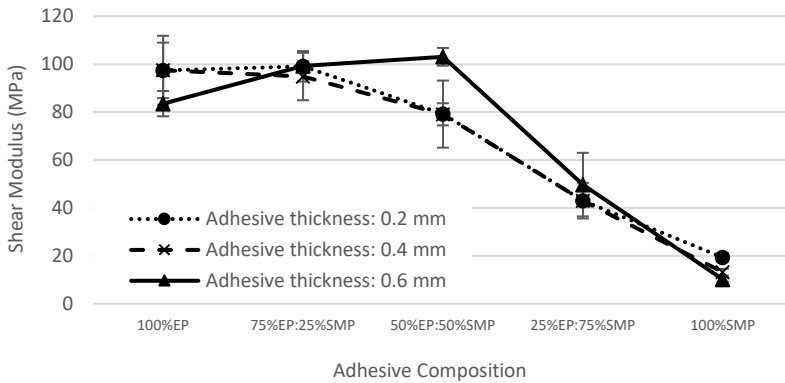


Figure 11: The shear modulus of the mixed adhesive joint EP-SMP in single lap joint aluminum

## Conclusions

Shear strength of mixed adhesive joints (MAJ) silyl modified polymer (SMP)–epoxy (EP) in a single lap joint (SLJ) aluminum to aluminum has been investigated. The addition of silyl modified polymer to epoxy decreases the shear strength and the shear modulus but increases the elongation of the mixed adhesive joints. The mixed-adhesive joint of 25%SMP:75%EP has the highest shear strength, even it is higher than that of the adhesive joint of 100%EP. There is no significant effect of adhesive thickness on the joint properties in the range 0.2 mm to 0.6 mm.

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