Displacement Behavior of Single-lap Joints Made from Functionally Graded Polymeric Materials

Mine Uslu Uysal

Abstract: ***For adhesively bonded joint security and long-term use of the joint, a precise stress analysis must be performed on single-lap joints. A single-lap joint, formed by joining two layers at a given lap length, is the most widely used adhesive joint type in practice. Nowadays, it is stated that the mechanical properties and joint strength can be increased by adding clay and graphite to the polymeric material used in single-lap joints, trying to estimate the joint strength for various loading conditions. This paper focuses on the bending moment behavior of a single-lap joint composed of newly designed functionally graded polymeric materials (FGPMs). For this purpose, the single-lap joint geometry subject to a bending moment is discussed. However, it is assumed that the bonded beams in the connection are composed of FGPMs. The beams are modeled using a new recently developed FGPMs. FGPMs forming the glued beams was obtained by adding PAM 96/98 and PV 60/65 graphite powders in epoxy resin at 3%, 6%, 9% and 12% volume ratios. The effects of graphite type and graphite volume ratio on maximum displacements were investigated in the joint subjected to bending moment. In addition, peeling stress (σ_y), Shear stress (τ_{xy}) and also von-Mises stress (σ_{von}) occurring in the mid-plane of adhesive layer with PAM 96/98 and PV 60/65 graphite powder added were determined for each volume ratio and presented in graphs.***

Keywords: ***Single Lap Joints, Functionally Graded Polymeric Materials, Adhesively Bonded Beam, Finite Element Method.***

I. INTRODUCTION

Creating a graded microstructure, producing functionally graded polymeric material (FGPM), is a very effective method to improve material properties. The microstructure change in FGPM makes the material different from homogeneous material and traditional composite material. There are different microstructure phases with different functions within FGPM and the overall structure of FGPM shows graded property due to these different phases. Since the material properties are in a regular and continuous change from one phase to the other, interface problems are eliminated. These graded materials have many advantages over homogeneous isotropic and composite materials in applications requiring durability [1,2]. In polymer materials, microstructure grading is done to provide an optimal combination of important material properties such as weight, toughness, surface hardness, peel resistance and impact resistance. Functionally graded polymeric materials can be produced by adding various reinforcing materials such as carbon fiber [3] [4] [5], silicon carbide [6,7], glass [8] and polyurethane [9] to epoxy resin.

Although bolts, rivets and different welding techniques are used in joining metals, the use of bolts, rivets and welding techniques in functionally graded materials significantly reduces material strength. Therefore, it is important to develop bonding technology for joints made of functionally graded materials.

Studies on single lap joints, which are both effective and simple connection types, are frequently encountered in the literature. In the analysis of these joints, the adhesive layer properties in the joint are generally considered homogeneous isotropic. In line with this assumption, the joint strength, shear and peel stress distribution are calculated. However, in order to develop more effective, stronger and lighter connections, the real-life conditions of the connections should be taken into account [10]. Many methods for adhesive joints have been proposed in the literature [11] [12] [13] [14].

This study deals with the use of the FDPM model, which has been experimentally developed recently, in order to improve its mechanical, electrical and magnetic properties, in adhesive bonds. The FDPM model was obtained by adding PAM 96/98 and PV 60/65 graphite powders in epoxy resin at 3%, 6%, 9% and 12% volume ratio and produced by centrifugal casting method. Investigations on the bending moment behavior of single-lap joints consisting of newly designed beams were carried out. In this way, it has been tried to contribute to the glued FDPM researches.

II. SINGLE-LAP JOINTS MADE FROM FGMPS UNDER BENDING MOMENT

In this section, the single-lap connection made from FDPM was subjected to bending moment. In the analyses, the bending moment value was selected as M = 9.81 Nmm. The boundary conditions and geometry of the single overlap joint made of FDPM with bending moment are given in Fig. 1. The length and thickness values in the connection geometry are 2l = 16 mm, a = 32 mm, η (the thickness of the adhesive) = 0.32 mm and t (the thickness of the top and bottom glued material) = 1.6 mm.

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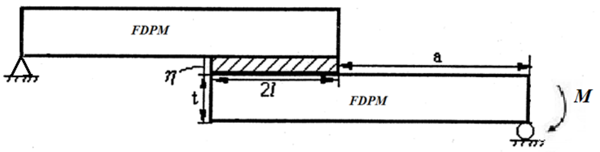

Fig. 1.Single overlap connection made of FDPMs under bending moment

In this paper, two types of single-lap joints are modeled. The first of these models consists of beams consisting of PAM96/98-PAM96/98 graphite powder added material, while the other consists of beams with PV60/65-PV60/65 graphite powder added.

ANSYS® finite element software was used in order to determine the stresses and stress distributions in single-lap joints made of FDPM under bending moment.

III. NUMERICAL RESULTS AND DISCUSSIONS

The maximum displacements that occur when bending moment is applied to the single-lap joints made of FDPMs are given in Fig. 2 and Fig. 3. It is seen that the maximum U_y and U_x displacement values due to bending moment are less than the single overlap joints without graphite powder. In Fig. 3, the displacement of the joint without PAM and PV graphite powder added was 18.5 mm, while the displacement value was about 15.5 mm for joints with graphite powder added by 12% by volume.

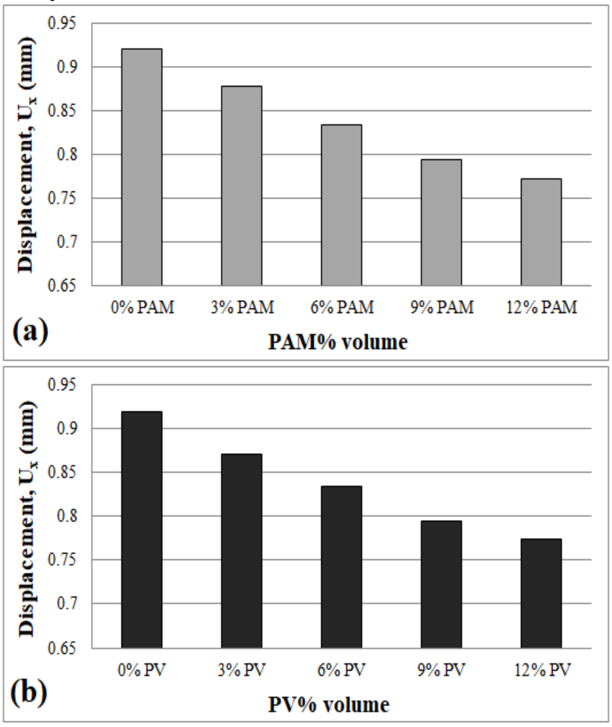

Fig. 2.The effect of graphite volume ratio on U_x displacement in a single overlap joint made of FDPMs under bending moment, a) PAM-PAM, b) PV-PV

The maximum deflection, U_y, values caused by bending moment were compared with U_y values of joints where no graphite powder was added. The maximum deflection value of the 3% PAM-PAM single overlap joint is 4.7% less than the maximum deflection value of the joint with no graphite powder added. This reduction amount is around 5.4% for 3% PV-PV.

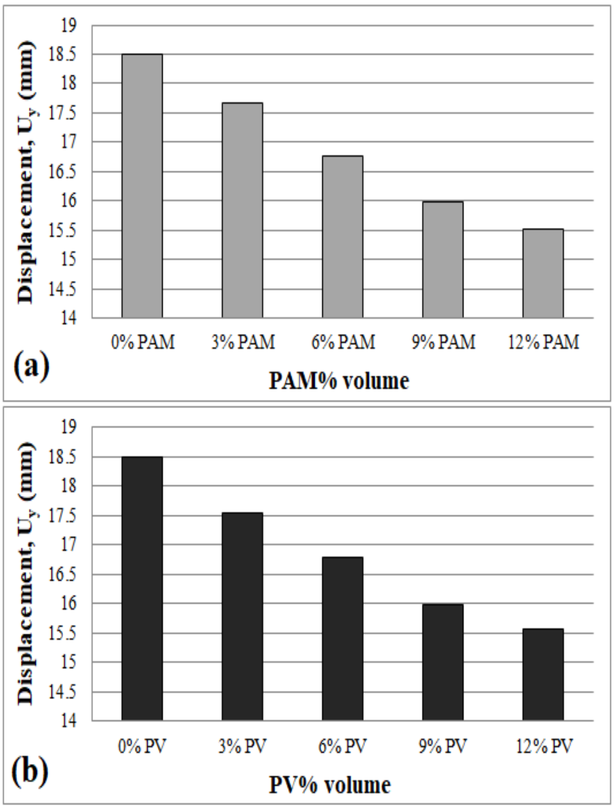

Fig. 3.The effect of graphite volume ratio on U_y displacement in a single overlap joint made of FDPMs under bending moment, a) PAM-PAM, b) PV-PV

The results of the stress analysis on the adhesive layer are important in terms of examining the bond strength and the rupture behavior of the bonded geometry. The maximum peeling (σ_y), shear (τ_{xy}) and von-Mises (σ_{von}) stress values occurring in the middle plane of the adhesive material shown in Fig. 4 were determined as a result of the finite element analysis.

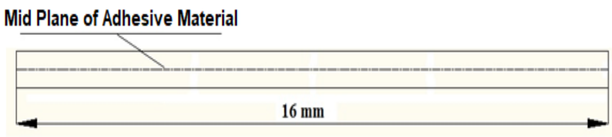

Fig. 4.The mid plane chosen for determining the stresses on the adhesive

In Fig. 5 and Fig. 6, the effects of the added graphite type and volume ratio on the stresses on the adhesive in a single-lap joint made of FDPM subjected to bending moment are given.

Fig. 5 shows how the maximum stresses on the adhesive are affected by the graphite volume ratio in single-lap joints with PAM graphite powder added under the effect of bending moment. When the graphite volume ratio increased by 3%, 6%, 9% and 12%, the von-Mises (σ_{von}) and peeling stresses (σ_y) in the joint increased.

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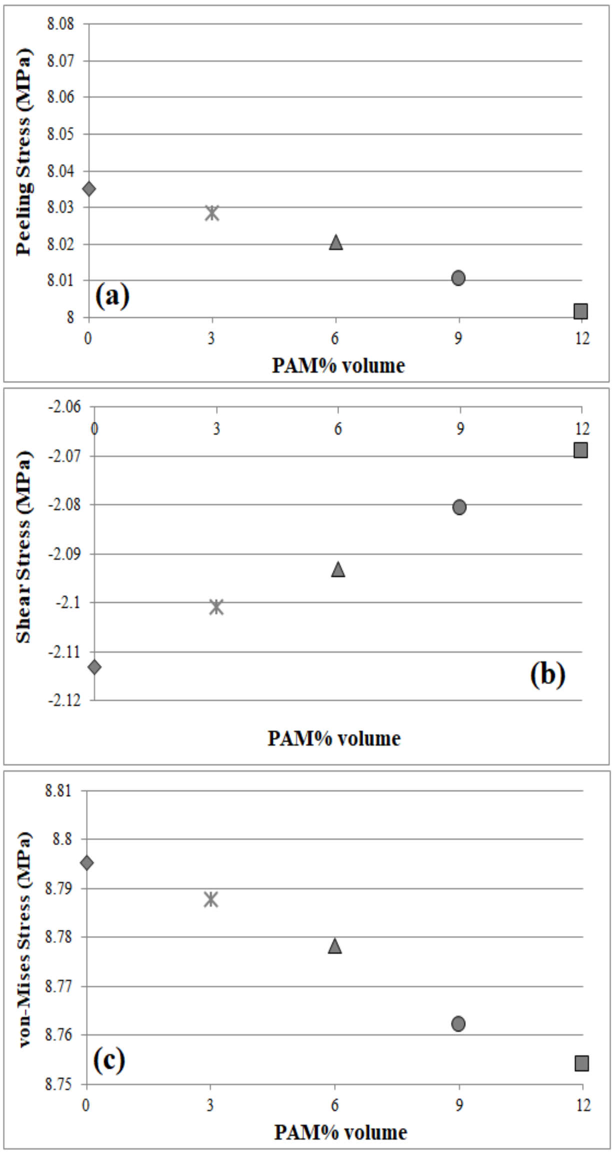

Fig. 5.The effects of PAM volume ratio on stresses in a single-lap joint made of FDPMs under bending moment, a) Peeling stress (σ_y), b) Shear stress (τ_{xy}), c) von-Mises stress (σ_{von})

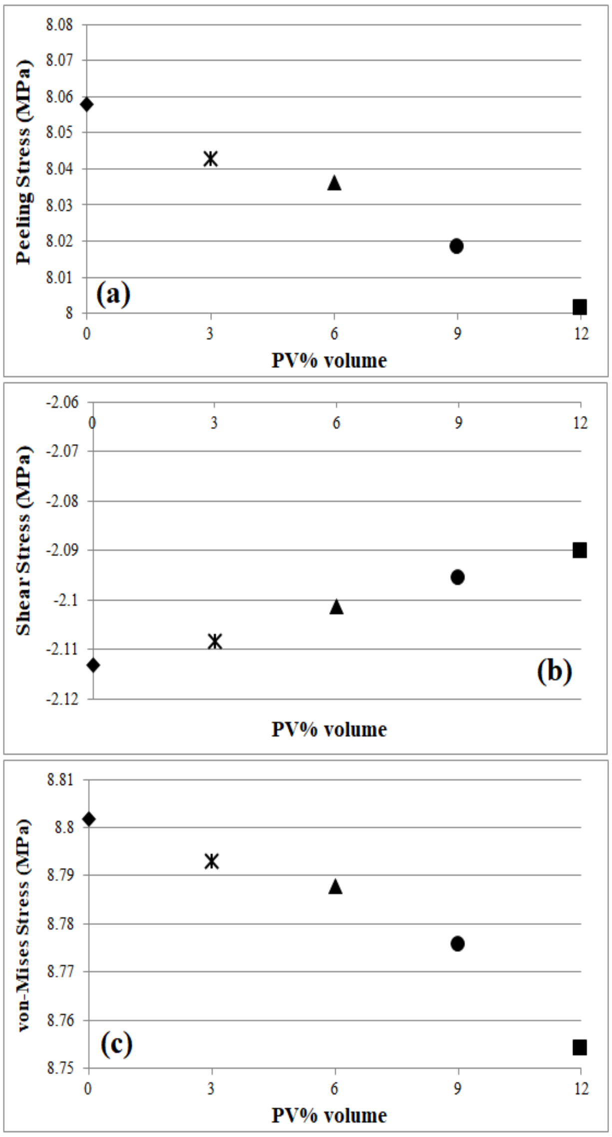

Fig. 6.The effects of PV volume ratio on stresses in a single-lap joint made of FDPMs under bending moment, a) Peeling stress (σ_y), b) Shear stress (τ_{xy}), c) von-Mises stress (σ_{von})

In Fig. 6, stresses occurring in the adhesive mid plane of single-lap joints containing PV graphite powder under bending moment are given comparatively. While the von-Mises stress value was 8.79 MPa at 3% PV joint, it decreased to 8.54 MPa by increasing the graphite volume ratio to 12%.

Analysis results showed that the strengths of single-lap joints made of FDPM formed by adding graphite powder into epoxy resin and grading are higher than single-lap joints without graphite powder added. Considering the stress values, the highest values, i.e. the worst joint strength, are seen in the connection type without graphite powder, which is indicated by 0%. However, it was observed that the stress values decreased as the added graphite powder volume increased. These results revealed that the added graphite powders helped to improve the mechanical properties of the resin and increased the strength.

IV. CONCLUSION

In this paper the behavior of heterogeneous adhesive bonds was modeled in one way. The recently developed FGPM model was used in the bonded materials. Due to their superior mechanical, thermal, electrical and magnetic properties, as well as their lightness and durability with adhesive joints made of FGPM, they are used in the aerospace industry (layered connections in aircraft and shuttle bodies), land and sea transportation (at junctions in car/ship frames) electronics and computers (surfaces of magnetic storage units, electromechanical sensors). Studies on adhesive bonds made of FGPM with different loads and different joint geometry are rare in the literature. For single lap joints subjected to bending moment, the following significant findings were obtained.

- On the adhesive layer, high shear stress concentrations were observed near the end points of the joint length where the adhesive started to separate.
- For PV60/65 and PAM 96/98 graphite powders, it was observed that the single lap joint strength increased at increasing volume ratios (3%, 6%, 9% and 12%).
- The best joint strength was seen in a single lap joint containing 12% by volume PV60/65 graphite powder. This showed that PV60/65 graphite powder was more compatible with resin than PAM 96/98 graphite powder.
- This study confirmed that the mechanical properties of the resin improved and the bond strength increased with the addition of graphite powders.

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Dr. Mine Uslu Uysal, was born in Eskisehir, Turkey in 1983. She received the B.E. and M.Sc. degrees in Mechanical Engineering from Pamukkale University (Denizli, Turkey) in 2005 and 2010, respectively and the Ph.D. degree in Mechanical Engineering from Yildiz Technical University (Istanbul, Turkey) in 2015. In 2009, she joined the Department of Mechanical Engineering, Yildiz Technical University as Research and Teaching Assistant. Dr. Uysal was visiting scholar in Institute of Sustainable Manufacturing, University of Kentucky between September, 2017 and September, 2018. Since 2019, she has been Faculty Member. Her current research area are solid mechanics, adhesively bonded structures and finite element analysis.

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