Cyclic stress-strain response of joints reinforced by shape memory alloys

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Abstract

The mechanical properties of adhesive joints are very sensitive to temperature and these types of joints which are subjected to high temperature, lose their strength. Therefore, the improvement of adhesive joints' thermal resistance is highly desired. In this study, creep phenomena in single-strap adhesive joints are considered and the effect of reinforcing the joints by shape memory alloy (SMA) on the creep behavior and the lifetime of the joints are studied experimentally. The effects of temperature and wires volume fraction on the joints creep behavior are also considered. For this purpose, several single-strap adhesive joints are reinforced by SMA in the shape of wires. The epoxy used in the adhesive joints is Araldite 2015 and NiTi shape memory wires with various volume fractions ranges from 0.5% to 2% are embedded into the adhesive. The creep tests are conducted at temperatures of 100 °C, 120 °C and 135 °C which all are above the glass transition temperature of the adhesive. By using SMA wires, a significant improvement in the adhesive joints creep properties could be achieved.

Keywords

Index Te*rms*—Shape memory alloy (SMA); Creep; Joint design.

1. .Introduction

Due to their great structural properties such as having more uniform distribution of loads, less stress concentrations and the edge factors, lighter weight and greater fatigue properties comparing to other traditional mechanical fastening and joints, the usage of adhesive joints is widely deployed in various industrial applications[1]. Adhesive joints are subjected to low or high temperature conditions in many applications and many researchers have tried to develop suitable models in order to describe the thermal and mechanical properties of adhesives at such temperatures[2]; [3];[4].Dean[5] worked on the creep behavior of an adhesive joint and studied the humidity effect on the adhesive model. Goland and Reissner [6] tried to predict the bending deflections in a single-lap joint according to Green′s function. They considered a beam model and simulated the joint as two beams bonded with an adhesive layer and subsequently found equations representing the peel and shear stresses in the adhesive layer. They also showed the importance of the peel stress in the joint failure.

Although the creep behavior in adhesive joints and also in shape memory alloys has been investigated by a few researchers, the creep behavior of single-strap joints which are reinforced by shape memory alloys has not been investigated. In the present work, by considering the published research works, the creep phenomena of single-strap adhesive joints reinforced by NiTi shape memory wires at the temperatures higher than the adhesive glass transition temperature is studied experimentally and the effect of temperature and the SMA's volume fraction on the creep behavior such as the time to failure and the creep compliance of the reinforced joints are obtained.

2. Experimental Procedure

2.1 Materials

Detailed dimensions of adhesive joints reinforced by six SMA wires are shown in Fig. 1.

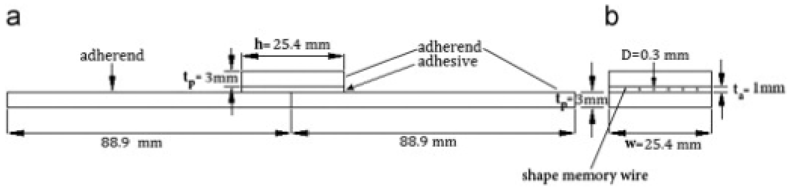

Fig 1. Detailed dimensions of single-strap adhesive joint reinforced by six SMA wires, (a) front view (b) side view.

The adherends were cut by laser and a mechanical machining procedure at the adherends edges was applied in order to have the same geometrical dimensions as denoted in Fig. 1.

In order to prepare the lap shear specimens, the adhesives and also the wires were placed with exact gap distance between the wires, using a specific engineered fixture shown in Fig. 2, with the accuracy of 0.01 mm prior to bonding the adherends.

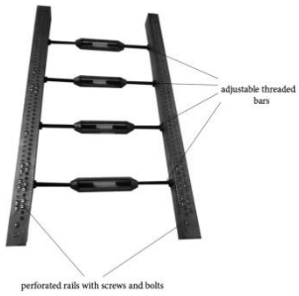

Fig 2. Specific engineered fixture for placing SMA wires.

Fig 3. The Torsee creep and rupture testing machine.

2.2 Preparation of the specimens for creep test

The machine used for the creep tests was a Torsee Creep and Rupture Testing machine (Tokyo, Japan). The machine has: three special heat elements with variable controllable heating power for adjusting the temperature; a loading mechanism in which variable mass units enable the loading; and a strain measuring system with an accuracy of 0.01 mm (Fig. 3).

The specimens were cured at room temperature for at least 7 days. This curing cycle is recommended by the adhesive manufacturer. Before conducting the tests and after finishing the curing process, in order to eliminate the edge effects of the adhesives in the tests, the additional adhesive fillets were removed (Fig. 4).

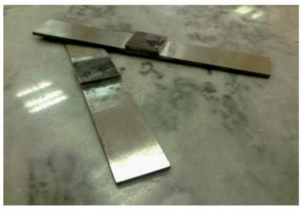

Fig 4. Specimens prepared for the creep testing.

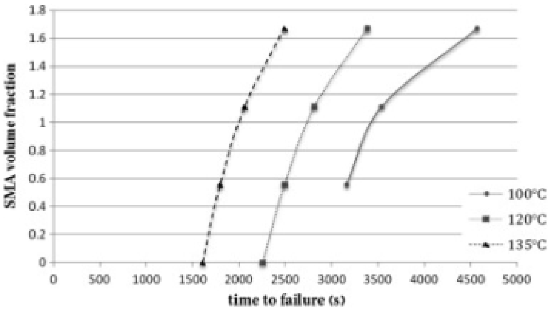

Fig 5. SMA wires volume fraction effect on the specimen's time to failure at different creep temperatures.

2.3 Creep tests

Considering the temperatures of 100 ℃, 120 ℃ and 135 ℃ for the creep tests, the specimens were inserted inside the machine creep chamber. After heating the chamber and the specimens to the specified temperatures, load was gradually applied to the specimens. In order to make sure that the results are reproducible, at least three specimens were prepared and tested for each condition.

3. Results And Discussion

In Fig. 5, the effect of the variation of the volume fraction on the specimens time to failure can be seen at different temperatures. The time to failure increases with increasing volume fraction of the SMA wires and decreases at higher test temperatures with the effect of temperature being more dominant.

The creep curves of adhesive joints at different temperatures in the form of creep strain history are shown in Fig. 6, Fig. 7 ; Fig. 8. In these figures, the creep strains in % versus time (joint creep strain rates) are illustrated with the total strains calculated using Eq. (2) presented in Table 4. All the three regions of the creep curves can be clearly observed in Fig. 6, Fig. 7 ; Fig. 8; the primary region with the rapid increase in the creep strains and decrease in the creep strain rates, the secondary region with the slight increase in the creep strains and constant creep strain rates and the tertiary region with the rapid increase of the creep strains and creep strain rates. From creep strain curves in Fig. 6, Fig. 7 ; Fig. 8, it can also be seen that the SMA wires could affect the adhesive creep behavior, especially in the tertiary regions.

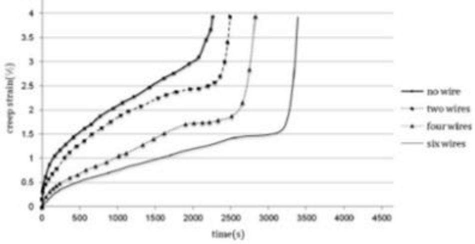

Fig 6. Creep behavior of the adhesive joints at 100 ℃.

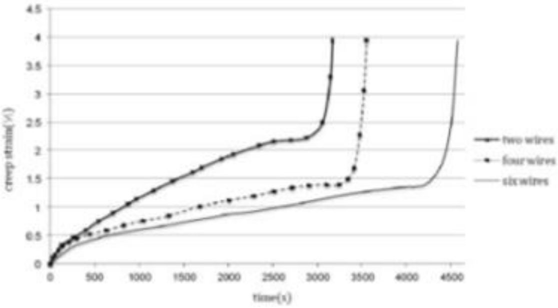

Fig 7. Creep behavior of the adhesive joints at 120 ℃.

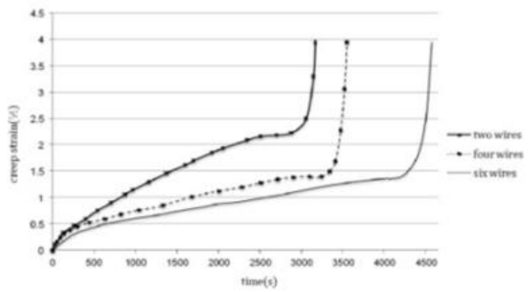

Fig 8. Creep behavior of the adhesive joints at 135 ℃.

The above figures (Fig. 6, Fig. 7 ; Fig. 8) reveal that the different SMA volume fractions at constant temperatures could affect the secondary and the tertiary regions of the creep response.

According to the results shown in Fig. 6, Fig. 7 ; Fig. 8, the creep strains are considerably decreased and since the compliance is directly related to the creep strain (Eq. 3), a decrease in the compliances of the specimens is achieved, which is a sign of higher stiffness and strength due to the presence of the wires.

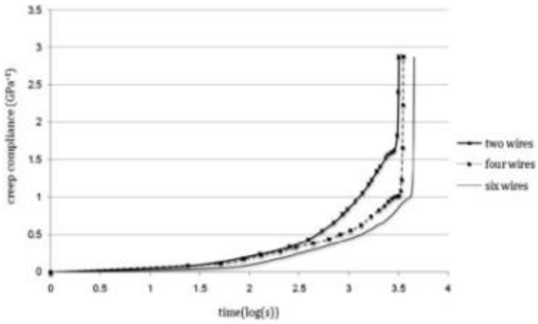

Fig 9. Compliance vs. log time for the adhesive joints at 100 ℃.

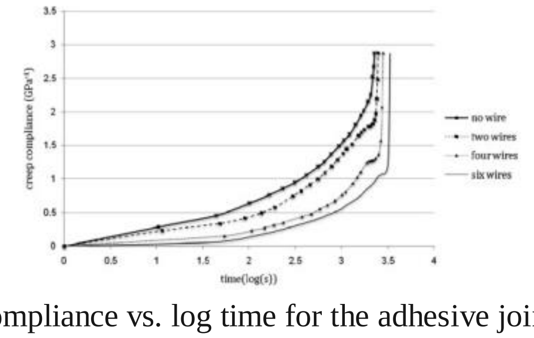

Fig 10. Compliance vs. log time for the adhesive joints at 120 ℃.

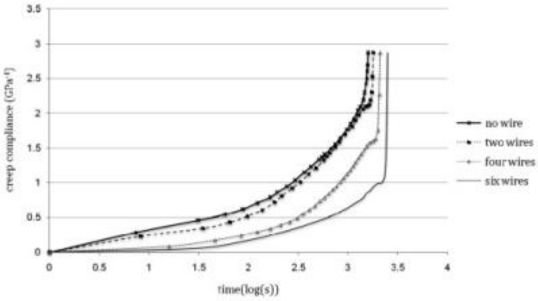

Fig 11. Compliance vs. log time for the adhesive joints at 135 ℃.

The compliance diagrams versus the logarithm of time for the joints is shown in Fig. 9, Fig. 10 ; Fig. 11. The effect of the SMA wires in the compliances of the reinforced specimens is clearly evident in these figures.

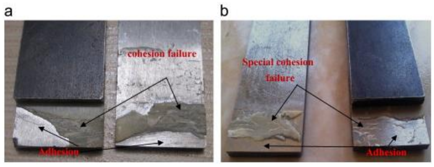

Fig 12. Fractured surfaces of un-reinforced adhesive joints tested at creep temperatures. (a) 120 ℃, (b) 135 ℃.

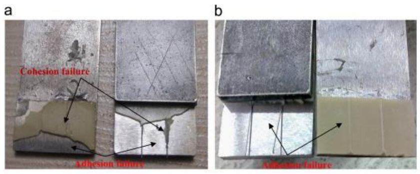

Fig 13. Fractured surfaces of two wires reinforced adhesive joints tested at creep temperatures. (a) 100 ℃, (b) 135 ℃.

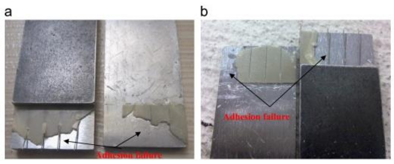

Fig 14. Fractured surfaces of four wires reinforced adhesive joints tested at creep temperatures. (a) 100 ℃, (b) 120 ℃.

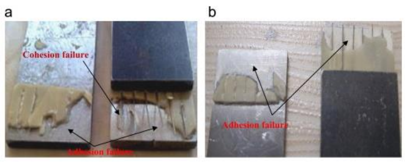

Fig 15. Fractured surfaces of six wires reinforced adhesive joints tested at creep temperatures. (a) 120 ℃, (b) 135 ℃.

The failure mode of the adhesive joints, as observed from the micrographs of the fractured surfaces of the specimens after the creep test, is a combination of adhesion and cohesion. The fractured surfaces of the specimens are shown in Fig. 12, Fig. 13, Fig. 14 ; Fig. 15. Fig. 12 shows the fractured surfaces of un-reinforced specimens and Fig. 13, Fig. 14 ; Fig. 15 show the fractured surfaces of the joints reinforced with SMA wires after creep tests at different temperatures.

Fig. 12, Fig. 13, Fig. 14 ; Fig. 15 show that failure tends to occur at the ends of the bonded area coinciding with the regions of critical (i.e. high tensile and shear) stresses.

4. Conclusion

In this work, single-strap adhesive joints with Araldite 2015 epoxy adhesives were reinforced by shape memory alloy (SMA) NiTi wires which were embedded into the adhesive and oriented as the applied load and were tested at three different temperatures, which were all higher than the adhesive glass transition temperature of the adhesive. The joint creep properties such as time to failure, compliance, etc, were studied experimentally. The effect of the SMA wires was more obvious in the tertiary region of the creep curves which could be explained by adjustment of the joints bending and peel and shear stresses due to presence of the SMA wires, which cause an extra friction between the wires and the adhesives.

Compared to the un-reinforced joint, the compliance of the reinforced joints was also improved. This is because of the direct relationship between the compliance and strain and this improvement is indicative of the higher stiffness and strength resulting from the presence of the SMA wires.

The work presented shows an effective way for improvement of the adhesive joints creep properties. It also opens a good opportunity of research on improving the joints behavior at high temperature conditions, by adding SMAs wires which are pre-stressed, reheated or any other actions that can affect and improve the joints creep properties.

Acknowledgements

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