Effect of main layer thickness on the response of multi layer bonded steel butt joint under Charpy impact test

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Abstract. The numerical analysis of the main layer thickness on the impact response of the steel butt joint bonded by multi-layer under the Charpy impact test is investigated using the elasto-plastic finite element method (FEM). The results obtained from numerical simulation show that both the elastic strain and plastic strain occurred at the point near the upper or lower surface decreased significantly when the main layer thickness increased from 0.1 mm to 0.4 mm. The value of the normal stress $S_x$ and the von Mises equivalent stress $S_{eq}$ increased first when the main layer thickness increased and then it decreased significantly when the main layer thickness is greater than 0.2 mm. There is a strong value fluctuation for stress $S_{eq}$ at the point 0.5 mm away from the upper surface when the main layer thickness is greater than 0.2 mm.

1 Introduction

The influence of the adhesive thickness is significant on the adhesively bonded metal joints [1-2]. In recent years, some investigations related to the impact properties of the adhesively bonded metal joint have been done [3-5]. The effect of the adheres thickness, elastic modulus of the adheres on the butt joint was investigated by the finite element method [3]. The FEM method was also applied to study the failure procedure of the adheres [4]. The effect of notch depth [5] as well as the multi-layer [6] under Izod impact testing on the impact response of the adhesively bonded steel butt-joint was investigated and it was found that the impact energy absorbed by unit area of joint is increased as the notch depth increased. The effect of multi-layer on the stress distribution in adhesively bonded single lap aluminium joint [7] was significant. The aim of this work is to study the effect of multi-layer on the impact response of the steel butt-joint under the Charpy impact testing.

2 Establishment of the model

The diagram of Charpy impact test and the multi layer is shown in Fig. 1. The properties of the materials used in the study are listed in the Table 1. The specimen for impact test modelling is in accordance with GB/T 19748 was bonded by a sandwich (primer Phenolic-main layer Epoxy- primer Phenolic, A-B-A for short) adhesive multi-layer as shown in Fig. 1b. The adherends were made from Q235 structural steel and the two halves of specimen (length 27.3 mm, width 10 mm and thickness 10 mm) was bonded with a multi adhesive layer consisted of two primer with the thickness of 0.1 mm and a main layer with the thickness of 0.1 mm, 0.2 mm, 0.3 mm and 0.4 mm respectively. The impact time was set as 0.2 ms with an initial velocity of 3.2 m/s. The finite element model was built using the ANSYS/ LS-DYNA software as shown in Fig.2. The eight-node hexahedral element Solid164 was used for both adhesive layer and adherend and it was restrained in Y direction by two supports. Two typical nodes are marked as P (x=0, y=4.5 mm, z=0) and Q (x=0, y= -4.5 mm, z=0) in Fig. 2c (0.5 mm away from the upper or lower surface respectively) for analyzing the response of the bondline under the Charpy impact test.

Table 1. Materials properties.

| Materials   | Elastic Modulus (MPa) | Poisson’s Ratio | Yield Strength (MPa) | Tang Modulus (MPa) |
|-------------|-----------------------|-----------------|----------------------|--------------------|
| Steel Q235  | 203,000               | 0.27            | 235                  | 6100               |
| A (Phenolic | 2,875                 | 0.42            | 90                   | 500                |
| B (Epoxy Resin) | 1,888            | 0.33            | 50                   | 50                 |

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3 Results and discussion

3.1 The response of strain after impact

The effect of the main layer thickness on the impact response with time at the point P (0.5 mm away from the upper surface) and Q (0.5 mm away from the lower surface) under Charpy impact test is shown in Fig. 3. It can be seen from the figure that both the elastic strain occurred at P or Q is increased rapidly after about 0.04 ms of time lap to a certain value (about 0.072 ms the elastic strain reached to 0.0364) and then the increase becomes slowly (Fig. 3a and 3c) but the increase of the plastic strain is steadily vs. time (Fig. 3b and Fig. 3d). In general, both the elastic strain and plastic strain at the node P is increased first and then it is decreased as the main layer thickness increased from 0.1 mm to 0.4 mm. And the strain of the multi layer with a 0.2 mm thick main layer is the greatest after 0.1 ms. The delay time of the elastic strain response is longer when the main layer thickness is increased. At node Q the highest elastic or plastic strain occurred in the multi layer with a 0.3 mm thickness after 0.12 ms meanwhile the lowest strain occurred in the bondline of the multi layer with a 0.1 mm thick main layer.

Figure 1. Diagram of the Charpy impact testing (a) and the multi layer (b).

Figure 2. (a) Model of FEM, (b) mesh for the multi-layer bonded butt joint and (c) the location of the node P and Q [6].

Figure 3. The effect of main layer thickness and the node on the strain vs. time: node P (a) & (b), node Q (c) & (d).
3.2 The response of stress after impact

The effect of the main layer thickness on the normal stress $S_x$ and von Mises equivalent stress $S_{eqv}$ response with the time at the point P and Q under Charpy impact test is shown in Fig. 4. It can be seen from the figure that the response of stress $S_x$ and $S_{eqv}$ at the point P and Q is also significantly affected by the main layer thickness. When the main layer thickness increased from 0.1 mm to 0.4 mm, the absolute values of the stress $S_x$ response at node P and Q decreased greatly and the response time became longer (Fig. 4a and 4c). When the time is longer than 0.1 ms, the von Mises equivalent stress $S_{eqv}$ at node P present a strong stress fluctuation especially for the main layer is thicker than 0.2 mm (Fig. 4b). The von Mises equivalent stress $S_{eqv}$ occurred at node Q (Fig. 4d) is much different from the stress $S_{eqv}$ occurred at node P. The value of stress $S_{eqv}$ is decreased first and then increased again as the thickness increase to a value of 0.4 mm. It is Increased evidently when the main layer thickness reached 0.4 mm to a value greater than 50 MPa (Fig. 4d).

![Figure 4](image-url)

Figure 4. The effect of main layer thickness and the node on the normal stress and von Mises equivalent stress vs. time: node P (a) & (b), node Q (c) & (d).

4 Summary

Under the study condition of this work, the results obtained from the numerical modelling show that the impact response of the butt-joint bonded by multi-layer bondline is evidently affected by the main layer thickness under the Charpy impact test. The absolute values of the stress $S_x$ response at node P and Q decreased greatly when the main layer thickness increased from 0.1 mm to 0.4 mm. There is a value fluctuation for the stress $S_{eqv}$ at the point 0.5 mm away from the upper surface when the main layer thickness is greater than 0.2 mm meanwhile the value of the stress $S_{eqv}$ at the point 0.5 mm away from the lower surface is decreased significantly except the 0.4 mm thick layer.

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References
1. L.F. Kawashita, A.J. Kinloch, D.R. Moore, J.G. Williams, Int. J Adhesion & Adhesives, 28, 199 (2008)
2. J. M. Arenas, J. J. Narbon, C. Alia, Int. J Adhesion & Adhesives, 30, 160 (2010)
3. M. You, J. Hu, X. Zheng, A. He, C. Chen, Advanced Materials Research, 230-232, 1350 (2011).
4. X. Zheng, L. Wu, M. You, K. Liu, M. Li, Advanced Materials Research, 602-604, 2279 (2013)
5. X. Zheng, M. Li, M. You, W. Liu, K. Liu, Advanced Materials Research, 644, 197 (2013)
6. J. Li, Y. Zhao, Y. Li, M. You, Materials Science Forum, 904, 68 (2017)
7. M. You, Y. Zhao, J. Li, Y. Li, Advanced Materials Research, 1061-1062, 471 (2015).