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Experimental investigation of the effect of adhesive thickness in adhesive joints under static and impact loading

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ABSTRACT

This paper presents an experimental study on the effect of adhesive thickness on the maximum load of adhesive joints under static and impact loading, using the double cantilever beam (DCB) test method. The DCB specimens were prepared with varying adhesive thicknesses and subjected to impact loading using a drop weight impact tester. The maximum load was recorded for each specimen. The results indicated that the maximum load of the adhesive joints increases with increasing adhesive thickness up to 5 mm, beyond which the maximum load decreases with further increase in adhesive thickness. Moreover, the failure mode of the adhesive joint was found to be strongly dependent on the adhesive thickness, with thicker adhesive layers exhibiting an adhesive failure mode but in thinner thicknesses, the adhesive mode is cohesive. These findings provide important insights into the design and optimization of adhesive joints for applications that are subject to impact loading.

1. Introduction

Adhesive bonding is a widely used method for joining materials in various industries. The strength and durability of adhesive joints depend on several factors, including adhesive properties, surface preparation, and joint geometry. However, the thickness of the adhesive layer is also an essential parameter that affects the joint's mechanical properties. Under dynamic loading conditions, such as impact loading, the effect of adhesive thickness on joint performance becomes more critical [1].

The effect of adhesive thickness on joint performance has been studied in many experimental and numerical studies. These studies have shown that a thinner adhesive layer can result in higher strength and stiffness of the joint, but it also increases the risk of adhesive failure. This is because the thinner adhesive layer allows for better contact between the adherents, resulting in a higher interfacial shear strength. A thicker adhesive layer, on the other hand, can provide better energy absorption capacity and reduce the risk of adhesive failure, but it may also reduce the joint's strength and stiffness [2].

As a result, the adhesive's viscoelastic behavior becomes more significant, and the joint's behavior becomes highly nonlinear. Additionally, the high loading rate can cause stress waves to propagate through the joint, leading to localized stress concentrations and potential failure modes that are not observed under static loading.

It is well documented that adhesive thickness influences strain rates under static conditions but these data are limited when it comes to large strain rates [3, 4]. Bezemer et al [5] loaded a stiff epoxy and a ductile polyurethane adhesive under shear using rod-ring specimens. Optimal thickness for energy absorption was 0.25 mm for epoxy and 1 mm for polyurethane. According to Goglio et al [6] research it was observed that a thickness of 0.5 mm provided greater strength compared to a thickness of 1 mm. Interestingly, these results align with what has been commonly observed during static testing, rigid adhesives exhibit peak performance when applied in layers approximately 0.2 mm

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thick. [3], while flexible adhesives work best when applied in thicker layers of around 1 mm [7].

These findings have important implications for various industries, particularly those that rely on adhesives for joining materials. It is crucial to choose the appropriate adhesive and thickness based on the application and the desired outcome. For instance, when using stiff adhesives, a thinner layer is more appropriate to ensure optimal strength, whereas for flexible adhesives, a thicker layer is necessary to achieve the desired result.

Yokoyama's research [8, 9] and a follow-up study with Shimizu [10], focused on pin-and-collar specimens that were bonded together using cyanoacrylate adhesive. Their research was aimed at identifying the ideal thickness for these specimens to ensure optimal performance. The results of their experiments indicated that the ideal thickness range for the adhesive joint was between 0.025 mm and 0.035 mm. This range falls below the maximum recommended adhesive joint thickness for anaerobic adhesives, which is 0.05 mm. These findings offer valuable insights for practitioners and manufacturers looking to achieve optimal bonding results in pin-and-collar specimens bonded with cyanoacrylate adhesive [11].

In this study, the effect of adhesive thickness on the mode-I fracture behavior of adhesive joints performance under static and impact loading was examined experimentally and numerically. DCB joints with different adhesive thicknesses were used to evaluate the joint's strength. Also Numerical simulations were used to validate experimental results and gain insights into the underlying mechanisms.

2. Specimen manufacturing

To determine the maximum load for the adhesive joints under mode-I loading, DCB specimens have been tested with different adhesive thicknesses. An adhesive joint was tested under static and impact loading in thicknesses of 0.25, 0.5, 0.8 and 1.1 mm. The dimensions of DCB specimen for static and impact loading are shown in fig 1 and 2 respectively. In impact loading, the impactor is released as a wedge from a certain height on the adhesive joint.

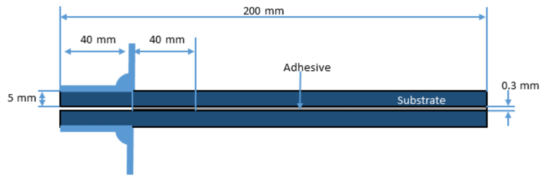

Figure 1: DCB specimen dimensions for static loading

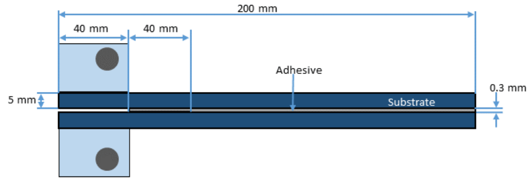

Figure 2: DCB specimen dimensions for impact loading

Al 7075-T6 substrates with an epoxy paste adhesive named UHU plus endfest 300 (UHU GmbH & Co. KG, Bühl, Germany) was used to manufacture DCB specimens. The Young's modulus and yield strength of the substrates were 71.7 GPa and 503 MPa, respectively. The adhesive had an operating temperature range of 40–80 °C, and its binder and hardener components had viscosities of 40 and 30 Pa·s, respectively [12]. A 1:1 ratio was used for mixing resin and hardener. In order to improve adhesion between the substrates and adhesive, the bonding surfaces of the substrates were prepared. The surface preparation consisted of acid etching in phosphoric acid for 30 minutes at 60°C, followed by washing with distilled water and drying in an oven. In order to control adhesive thickness, two wires were placed at the ends of each joint. The pre-crack was also provided by a 13-micrometer thick nonstick polyethylene film (figure 3).

Figure 3: Making an adhesive joint

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A uniform force was applied to the specimens according to Figure 4, and the adhesive joints were cured in an oven at 80 °C for 40 minutes. The curing temperature and time were considered according to the adhesive data sheet [12].

Figure 4: Manufacturing fixture

After the adhesive joint curing process, hinges and block attached to substrate for static and impact loading (figure 5).

Figure 5: Specimens for static and impact loading

3. Results and Discussion

3.1. Static loading

To study the effect of thicknesses in static loading, DCB specimens were tested on a SANTAM STM-150 universal testing machine (figure 6). Testing was conducted at a displacement rate of 0.5 mm/min under displacement control. In order to ensure the validity of the experimental results, each test was repeated four times.

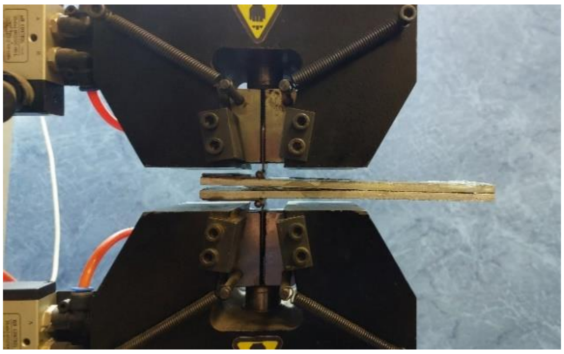

Figure 6: DCB static test setup.

The typical load-displacement curves of the adhesives with different thickness are shown in Figure 7. The results indicate that maximum load of the DCM adhesive joints in static loading improved by increasing up to 0.5 mm. However, the maximum load was decreased by further increasing the adhesive thickness.

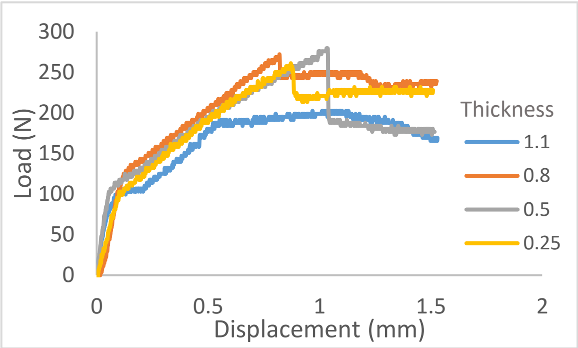

Figure 7: Load-displacement curves of the adhesive joints with different adhesive thickness in static loading

3.2. Impact loading

To study the effect of thicknesses in impact loading, DCB specimens were tested on a drop weight machine (figure 8). A wedge impactor with a weight of 2635 g hits the adhesive joint from a height of 20 cm.

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Figure 8: DCB impact test setup.

In Figure 9, the maximum load for static and impact loading are compared with each other. The results show that the maximum load increases under impact loading compared to static loading. The biggest increase is for adhesive joint with a thickness of 0.5 mm, which increases up to 918% in impact loading compared to static loading.

Also by observing the fracture surface with thicker adhesive layers exhibiting an adhesive failure mode but in thinner thicknesses, the adhesive failure mode is cohesive.

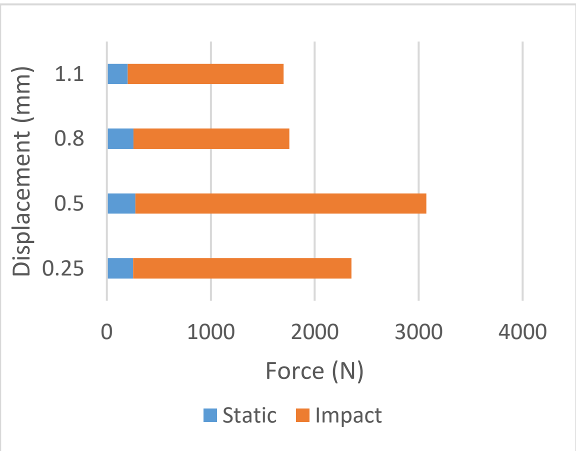

Figure 9: Comparison of maximum load in static and impact loading

4. Conclusions

The study of adhesive joints is of significant importance in the field of mechanical engineering, as adhesive joints has become an increasingly popular method of joining materials in various applications. Adhesive joints offer several advantages over traditional mechanical fastening methods, such as increased flexibility, better stress distribution, and improved aesthetics. However, the strength and reliability of adhesive joints depend on various factors, including the adhesive material properties, adhesive thickness and loading conditions.

In conclusion, this study investigated the effect of adhesive thickness on the performance of adhesive joints in mode_I fracture behavior under static and impact loading using the DCB specimen. The results revealed that the maximum load was observed in the 0.5 mm adhesive thickness, while the minimum load was observed in the 1.1 mm adhesive thickness in static and impact loading. Also the results show that the maximum load increases under impact loading compared to static loading. This suggests that the adhesive thickness plays a crucial role in determining the strength of adhesive joints under static and impact loading.

It is evident that the adhesive thickness affects the fracture behavior and failure mode of the adhesive joints, which can have significant implications for the structural integrity and safety of various engineering applications. Therefore, it is essential to carefully select the appropriate adhesive thickness for specific applications to ensure optimal performance and durability of the adhesive joints.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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