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Tolerance Analysis of Adhesive Bonds in Crash Simulation

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Abstract

The influences of geometrical parameters like adhesive layer thickness and gap-filling on the mechanical properties of adhesively bonded joints are investigated by means of experimental studies with controlled parameter variations. In addition, corresponding simulation models are used to analyse these effects. As a result, the behaviour of joints under variation of manufacturing parameters can be reproduced with high accuracy. Furthermore, the validated simulation models are used to perform sensitivity analysis on a component-like specimen. Based on these studies, tolerance ranges can be specified and robust design optimisation can be carried out.

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Keywords: adhesive bonds; crash simulation; sensitivity analysis; manufacturing tolerances

1. Introduction

The adhesive bonding as joining technology plays an important role in modern automotive industry. In particular, the use of structural adhesives in the car body improves the stiffness and crash performance significantly. In recent years, a number of material models for the design and calculation of adhesively bonded joints have been developed and implemented into FE-programs. However, in most FE analyses, deterministic parameters for adhesive bonds are used to predict crash behaviour. But in automotive mass production, geometrical discrepancies always occur affecting the mechanical properties of the joint significantly.

A lot of studies have investigated the influences of manufacturing parameters such as surface pre-treatment, overlap length, adherend and adhesive thickness on the behaviour of adhesive joints [1, 2, 3, 4]. It was found that some of the parameters affect the bonding strength and failure. However, previous studies are often limited to the experimental determination of the correlation between geometrical parameters and the mechanical behaviour of the joint. The objective of the present study is to present a method, how the influences of manufacturing tolerances like adhesive layer thickness and gap-filling can be considered in the FE-based dimensioning of adhesive joints.

2. Test specimens and setups

2.1. Materials and bonding procedure

The one component epoxy based, crash modified structural adhesive BETAMATE 1496 V from DOW Automotive is used for all specimens. The curing schedule of 30 min at 180 °C is adapted to the cathodic dip coating process.

The butt joint specimen (BJS) in Fig. 1 and thick adherent single lap shear specimen (TASS) in Fig. 2 are suited to study the influence of the adhesive layer thickness on the strength and failure of the joint under tension and shear loading. The adherends of both specimens are made of ordinary steel St37k (material number 1.0037). To improve the adhesion, the bonding areas are pretreated with coated DELO-SACO-PLUS corundum grains.

The LWF-KS-2-peel specimen in Fig. 3 is used to investigate the so called gap-filling parameter *g*, which gives the amount of protruding adhesive at the end of the bonding area. The T-Joint specimen in Fig. 11 is used for the sensitivity analysis and the validation of the proposed method.

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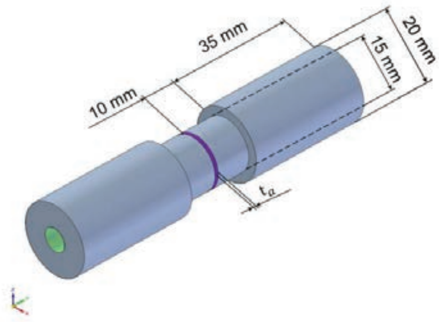

Fig. 1. Geometry of the butt joint specimen (BJS).

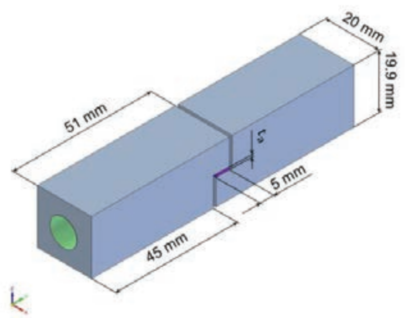

Fig. 2. Geometry of the thick adherent single lap shear specimen (TASS).

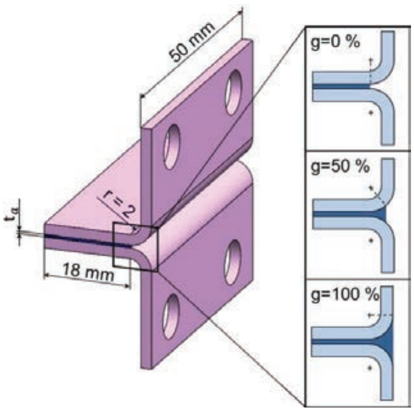

Fig. 3. LWF-KS-2-peel specimen and definition of gap-filling g.

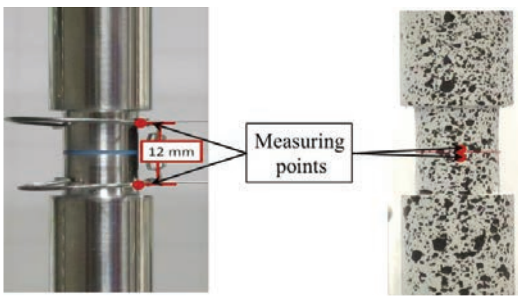

Fig. 4. Measuring points on the BJS for quasi-static (left) and dynamic load (right).

The microalloyed steel HX340LAD+Z100 (material number 1.0933) is used for the LWF-KS-2-peel and T-Joint specimen. Due to its good cold formability and yield strength in the range of 410-510 MPa, this steel is widely used for bodyshells. The adherends of the LWF-KS2-peel- and T-Joint specimen are degreased with isopropanol before bonding.

2.2. Specimen geometries and parameter variations

The geometries of the BJS and TASS are shown in Fig. 1 and Fig. 2. Due to the specimen geometries and the much stiffer adherends, the stress state in the adhesive layer in normal (BJS) and shear (TASS) direction is nearly homogeneous. Joints with four different adhesive layer thicknesses t_a are investigated: 0.15 mm, 0.3 mm, 0.6 mm and 1 mm.

The LWF-KS-2-peel specimen in Fig. 3 consists of two angled steel sheets with the overlap area of 18x50 mm². The adhesive layer thickness is 0.3 mm. Three different gap-fillings are investigated: 0 %, 50 % and 100 %. The manufacturing of different gap-fillings takes place by removing of the uncured adhesive with a spatula from the gap opening.

2.3. Testing

After curing, all specimens are stored for at least 10 days under standardized climate conditions (23°C room temperature and 50 % relative humidity) and tested afterwards. In order to identify the occurring variations, at least five specimens are tested for each joint and testing configuration.

The joints are tested with two quasi-static and two dynamic testing rates. The quasi-static tests are carried out with strain rates of 0.002 s^{-1} and 0.02 s^{-1}. The displacement is measured with a local extensometer directly on the specimen. The measuring tips are positioned centrally to the adhesive layer at a distance of 12 mm to each other (see Fig. 4, left). The corresponding testing machine velocity v_m is calculated as:

$$v_m = t_a \dot{\varepsilon}; \qquad v_m = t_a \dot{\gamma}$$

where t_a denotes the adhesive layer thickness and $\dot{\varepsilon}$ and $\dot{\gamma}$ the strain rates in normal and shear direction, respectively.

In the case of dynamic tests, the initial velocities are also calculated with the formula above according to the desired strain rates of 50 s^{-1} and 1000 s^{-1} of the dynamic test setup. For the local displacement measurement a high speed camera and an optical point tracking system called GOM are used. The position of the measuring points on the specimen is shown in Fig. 4, right. More details about specimens and setups can be also found in [11].

3. Experimental results

3.1. Layer thickness influence

Fig. 5 and Fig. 6 show stress-strain curves as results of the tests of the BJS and TASS specimen bonded with the four