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Delamination behaviour of high strength vibration damping sheet in V-bending test

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Abstract. High strength vibration damping sheet (VDS) consists of two high strength steel sheets and a viscoelastic polymer core with high vibrational damping characteristics. In this study, high strength VDSs with were fabricated with dual phase (DP) 590 steel sheets with 0.7mm of thickness as outer skins and polymer core with very thin thickness. To investigate the effect of different characteristics of the polymer core on delamination behaviour during press bending operation, three types of polymer cores were considered, which are polyethylene, epoxy and acrylic based adhesives and the V-bending tests were performed using the manufactured VDS. In addition, finite element analysis (FEA) was carried out to analyze the influence of the normal/shear directional characteristics of the polymer core on delamination behaviour in the V-bending test. As a result, it could be shown that different delamination behaviours were caused by the three types of the polymer core having different normal/shear directional characteristics.

Keywords: Vibration damping sheet, Polymer core, V-bending test, Delamination, Cohesive element

1. Introduction

The vibration damping sheet (VDS) which is manufactured by inserting a thin polymer core between two sheets has excellent vibration and noise attenuation characteristics due to the viscoelastic property of the inserted polymer core [1]. Recently, as demand for improved ride quality mainly influenced by the vibration and noise, several studies are underway to apply the VDS to automotive parts such as a dash panel, an oil pan or front floor. However, some defects are known to depend on the deformation behavior of the polymer core, such as a curl and delamination without failure can be observed during bending and drawing of the VDS. These problems have limited the introduction of VDS in several potential applications [2]. Hence, in order to understand the deformation behaviour of VDS in the forming process, the adhesive properties of the polymer core at the interface between two steel sheets should be known. Several researchers attempted to simulate the deformation behaviour of VDS using finite element analysis (FEA). The cohesive element whose thickness does not affect the critical time step for modelling the polymer core which has a very thin thickness was introduced [3,4]. FEA of the bending test for VDS was performed using the cohesive element to investigate the delamination and

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slip between two steel sheets [5] and the delamination behaviour of VDS during lap-shear test and T-peel test was analysed using FEA with the cohesive elements [6]. Despite many previous studies on the behaviour of VDS, most studies have been based on the assumption that the behaviour of VDS is largely influenced by the shear deformation of the polymer core [5,7], and there is no research on the detailed normal/shear directional adhesive properties of the polymer core using FEA.

The aim of this study is to investigate the effect of polymer cores with different adhesive properties on delamination in the V-bending test, and, moreover, to understand the effect of the normal/shear directional adhesive properties of the polymer core on the delamination behaviour of VDS. Three types of VDS were manufactured by bonding two steel sheets with three types of polymer cores with different characteristics and V-bending tests were performed to observe the delamination behaviour. These three types of delamination patterns were simulated using FEA with cohesive elements and the effect of the normal/shear directional adhesive properties of the polymer core on the delamination behaviour of VDS was analysed.

2. Experimental procedure

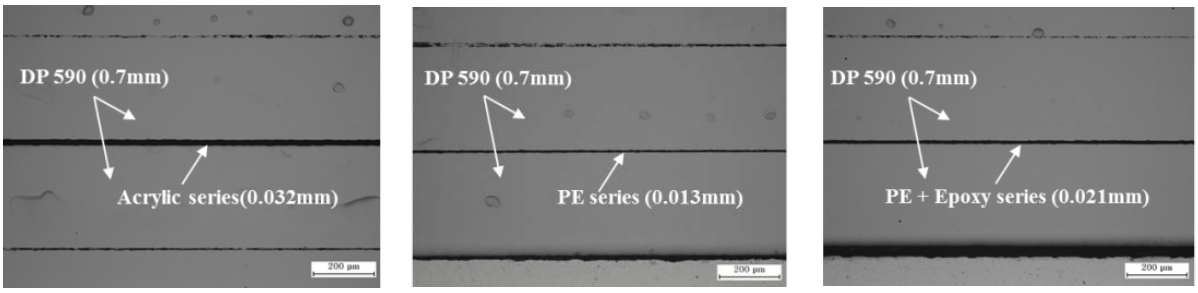
2.1. Materials

The base material in this study was dual phase (DP) 590 steel sheets which have a ferrite matrix containing martensite as a second phase with 0.7 mm thickness, supplied by POSCO. The mechanical properties of the DP590 steel sheet measured from the tensile tests along the rolling direction (RD) are presented in Table 1.

To observe the different delamination appearances with respect to the types of the polymer core, the three types of polymer core which were acrylic (ACRY.) based, polyethylene (PE.) based and polyethylene-epoxy (PEE.) based were used to manufacture VDSs. VDSs was fabricated by passing through roller after inserting polymer core between two DP steel sheets having size of 300mm x 300mm and then by being cured at 100℃ for 30 minutes. The thickness of the inserted polymer cores measured by the optical microscopic observation of the bonding section is shown in Figure 1.

Table 1. Mechanical properties of DP590 steel sheet

E (GPa)	YS (MPa)	UTS (MPa)	ε^{UTS} (%)	$\varepsilon^{fracture}$ (%)	R-value
210.3	351.4	649.8	19.2	27.5	0.88

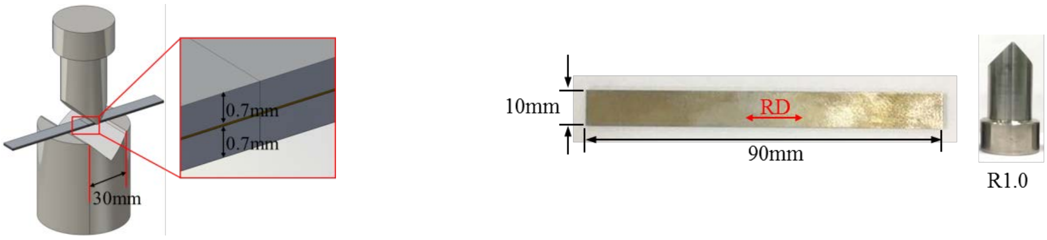


(a) (b) (c)

Figure 1. Cross section of the bonded area of the VDS: (a) acrylic based, (b) polyethylene based, (c) polyethylene-epoxy based

2.2. Test setup

The apparatus of the V-bending test used in this study is shown in Figure 2(a). The upper V-shaped punch pressed the lower V-shaped die to bend the specimen. The bending angle was 90 degrees and the end radius of the punch was 1.0 mm. The length of the V-shaped, so-called a die span, was 30 mm. The size of the specimen was 10 mm x 90 mm as shown in Figure 2(b). According to a study of conventional bending of adhesive-bonded sheet metals, if the length of the die-span is smaller than the length of the specimen, it is possible to prevent a delamination phenomenon in the middle part of specimen which is called a curl [5] or gull-wing bend [7]. In this study, the length of the specimen was made three times longer than the length of the die span which caused the delamination to occur intentionally. Real-time camera equipment was used to record the moment of delamination in the V-bending test. All tests were performed in a universal testing machine (UTM) at 0.1 mm/s constant cross head speed.

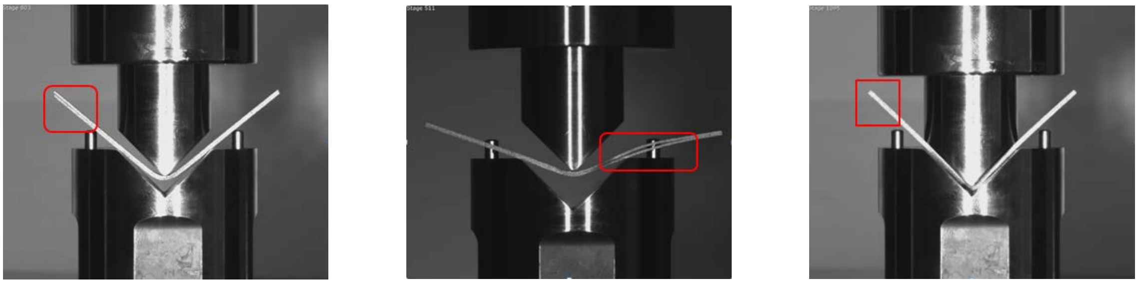


(a) (b)

Figure. 2 The apparatus of the V-bending test: (a) test tool setting, (b) the shape of specimen

3. Experimental observation

Figure 3 shows the delamination patterns of the V-bending test with respect to the three types of polymer core. The PE polymer core specimen was delaminated with curling the middle part of the specimen as shown in Figure 3(b). This phenomenon was mentioned in several previous papers [7–9]. When the VDS is subjected to bending tests, the two sheets are bent independently of each other with two different radii because the radii are different between the inside and the outside of the bend. This causes the sheets to slide relative to each other, so a shear stress develops in the polymer core along the length of the sheets. The shear stress induces moment and rise to the curl. As a result, the amount of curl depends on the characteristics of the polymer core if the base sheet is the same. In the delamination pattern of the ACRY polymer core specimen as shown in Figure 3(a), the curl did not rise and shear slip occurred between the two sheets at the end of the specimen. Since the shear stress that could cause relative sliding was much higher than the strength of the ACRY polymer core that constrained two sheets, a shear slip occurred between the two sheets. The PEE polymer core specimen did not exhibit delamination as shown in Figure 3(c).



(a) (b) (c)

Figure 3. The delamination patterns of the V-bending experiments: (a) ACRY polymer core, (b) PE polymer core, (c) PEE polymer core

4. Simulation procedure

4.1. Numerical modeling

The V-bending simulation was conducted using the commercial software LS-DYNA, version R910 [10]. The FE mesh of the assembly model is shown in Figure 4. Four-node quadrilateral shell elements were used for the mesh of the punch and die. The punch was meshed using 432 elements and the die was meshed using 1420 elements with a mesh size of 2.0 mm by 2.0 mm. The corner regions of the punch and die were finely split to 20 elements through length direction. The base sheets were meshed into eight-node hexahedron solid elements. They were discretized into 43,200 elements, each 0.25 mm by 0.25 mm by 0.1 mm. A surface-to-surface contact method was applied to handle the contact between the punch, die and the specimen. The friction coefficient was chosen to be 0.15 by assuming a conventional friction condition in sheet metal forming [11]. The punch and the die were treated as rigid bodies, whereas the specimen was modelled with deformable bodies. Since, the anisotropic effect of the material is not the main focus in this study, an isotropic elastic-plastic model was adopted for the base sheets for the sake of simplicity. In the case of the polymer core between the two base sheets, they were simulated using cohesive elements.

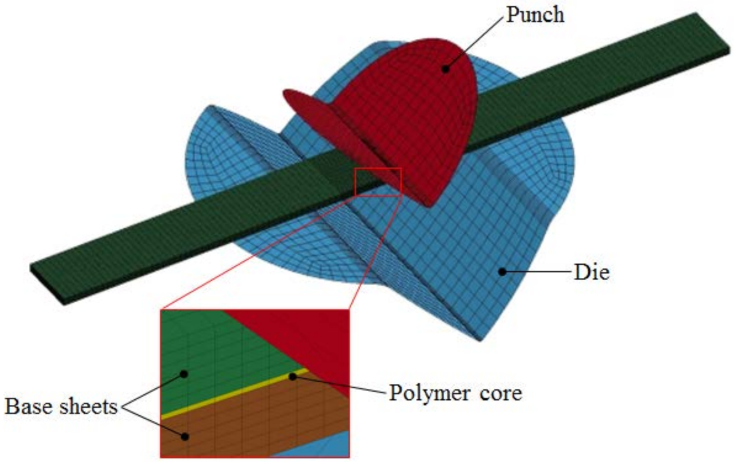


Figure 4. Finite element meshes of the V-bending test

4.2. Adhesive zone modeling

To take account of the polymer core having a very low thickness less than 0.03mm, the cohesive element was adopted. The preliminary simulations was performed considering varying thickness which had 0.01mm, 0.02mm and 0.03mm, to investigate the effect of the polymer core thickness on the delamination behaviour. As results, the delamination behaviour between varying thicknesses was not significant so that the specific thickness of the 0.03mm for the polymer core was selected to only analyze the effect of the normal/shear characteristic of the polymer core on the delamination behaviour. In the cohesive model, the traction-separation (T-S) curve is entered as a normal/shear directional mixed mode type to consider the characteristics of the normal and shear directions. Traction is the amount of adhesive strength per unit area, and separation is the displacement of the polymer core until just before the delamination occurs. In this study, MAT_138 model in LS-DYNA, considering a relatively simple T-S curve was adopted.

5. Results and discussions

In order to investigate the effect of the polymer core traction on delamination, the simulations were carried out under the following three conditions of the polymer core traction as shown in Figure 5. Case 1 had stronger traction of the normal direction than that of the shear direction, case 2 had stronger traction of the shear direction than that of the normal direction, and case 3 had tractions in both directions that were strong and equal.

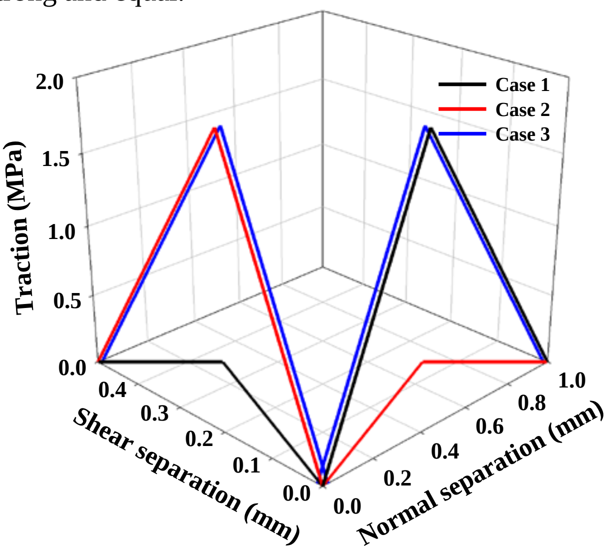
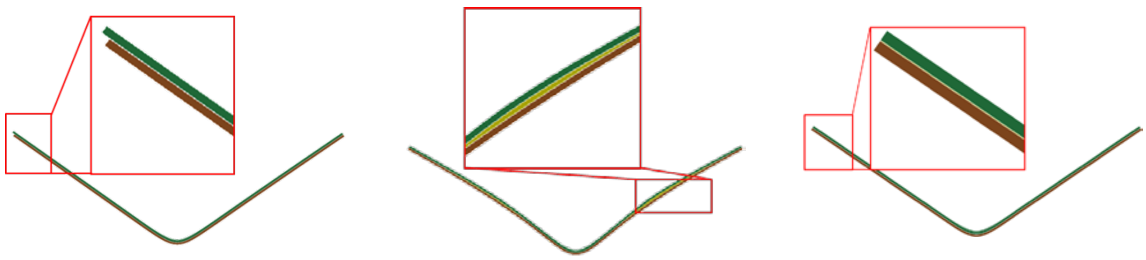


Figure 5. Normal/shear directional traction condition

The delamination patterns of the simulation are shown in Figure 6 with respect to the conditions. Looking at the delamination pattern of case 1, simulated with a lower shear traction as shown in Figure 6(a), the curl did not rise and the shear slip occurred between the two sheets at the end of the specimen. On the other hand, Figure 6(b) shows that the delamination with curling in the middle part of the specimen occurred in case 2 simulated with lower normal traction. In case 3 of Figure 6(c), delamination did not occur because the normal/shear directional tractions were sufficiently large. Comparing the delamination patterns of the previous experiments with the simulation delamination patterns, it can be seen that the delamination of the ACRY polymer occurred in terms of having lower shear strength than the normal strength as case 1 and the PE polymer specimen was delaminated by the lower normal strength than the shear strength similar to case 2. In other words, Case 1 and ACRY polymer specimen were delaminated by lower shear traction and case 2 and PE polymer specimen were delaminated by lower normal traction. These were defined as the shear delamination and the normal delamination, respectively. Hence, the characteristic of the ACRY polymer core and PE polymer core could be expected to have lower shear strength and lower normal strength respectively and the PEE polymer core could be predicted that the normal/shear directional strength were strong enough.



(a) (b) (c)

Figure 6. The delamination pattern of the V-bending simulations: (a) case1, (b) case2, (c) case3

6. Summary

The different delamination behaviours were caused by the three types of the polymer core. The delamination behaviours of VDS were divided into normal and shear direction depending on the normal and shear traction of the polymer core. When the normal traction of the polymer core was lower than the shear traction of that, the normal delamination occurred. The characteristic of the normal delamination was that the delamination took place with the curl phenomenon in the middle of the specimen, whereas if the shear traction of the polymer core was lower than the normal traction of that, the shear delamination occurred. The feature of shear delamination was that delamination took place with a shear slip.

Acknowledgments

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