Experimental Study of the Roll Forming of PVC / Glass Fabric Composite Laminates

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1-Introduction

Roll forming process is one of the most used methods to produce different metallic profiles with high speed and efficiency. Due to high interest in replacing metallic products by polymeric composites, this process can be used to produce composite laminates profiles efficiently. For this purpose, researchers have used semi crystalline thermoplastic matrix composite laminates in roll forming process which resulted in a lot of forming defects.

Amorphous thermoplastic PVC doesn't have a specific melting point and also recrystallization. So, it softens gradually by heating up without melting and also gets stiffer by cooling. Therefore, in comparison with semi crystalline thermoplastics, its formability is better and has a more forming temperature window. As a result, PVC based composite laminates also have a very good formability and can be formed with lower defects and difficulties. Besides higher formability, PVC based composite laminates have a very good mechanical properties and bonding strength between PVC and glass fibers due to polar functional groups of PVC matrix. Despite the advantages of amorphous thermoplastic PVC to increase the formability of composite laminates, there isn't any report on the formability study of this material. Therefore, in this research for the first time proper forming temperature of PVC/ woven glass fabric composite laminates are evaluated and roll forming of these materials are studied.

2-Experimentals Procedure and Design of Experiments

PVC thermoplastic films with thickness of 0.2mm, glass transition temperature (Tg) of 74°C and degradation temperature of 296°C are used as matrix phase of the composite laminates. Plain weave E glass fabrics with density of 200 g/m2 are also used as the reinforcing phase. Film stacking procedure is used to produce the composite laminates. Six glass fabrics with $[90/0]_6$ and $[-45/45]_6$ layups are alternately placed between 7 PVC films and by applying temperature of 230°C, pressure of 1.5 MPa during 5 minutes, consolidated composite laminates with thickness of 2.25mm are produced.

Firstly, samples with dimensions of 11×10 cm are prepared from the composite laminates, and press formed into channel section at different temperatures. Using optic microscope images of the bent cross section of the samples, it is determined that temperature of 160°C achieves as the proper forming temperature of the composite laminates.

A conventional 7 stand roll forming machine with some modifications is used for the roll forming of the composite laminates. An oven is installed before the forming stands which the samples with dimension of 80×12 cm are heated up to 170°C during 10 minutes and then are fed between forming rolls. A water spray cooling system is also installed at the end of the machine which is used to cool down the formed samples rapidly. Forming is done with a linear speed of 40 mm/second using rolls of 185mm diameter and stands distances of 375mm.

Single stand roll forming with forming angles of 30, 45 and 60 degrees are done to determine the flower pattern of the process. Later, multi stands roll forming with forming angles of 0, 30, 60 and 86 degrees are done for both layups to produce channel sections with two different dimensions. Three single stands and two multi stands roll forming for each of the layups result in 10 roll forming conditions. Geometrical defects including spring back, flange waviness and warping are measured for each of the samples. These defects are illustrated in Fig. 1.

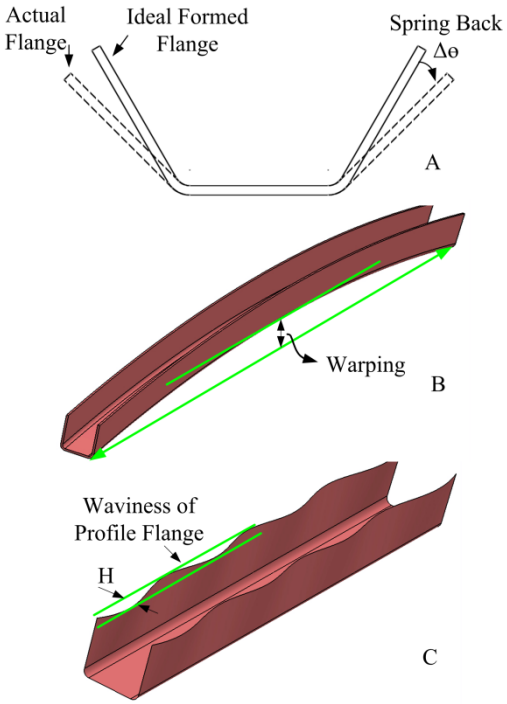

Fig. 1. Roll forming defects A: spring back, B: warping and C: flange waviness

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3-Results and Discussions

Forming Temperatures

According to the microscopic images of the press formed samples, forming at low temperatures results in buckling of fibers in the inner surface of bend region (compressive strains region). This defect reduces products strength and quality. Increase of forming temperature reduces this defect and at temperature of 160°C forming is done without any fibers buckling or wrinkling. Optic microscope images of 160°C press formed samples are shown in Fig. 2.

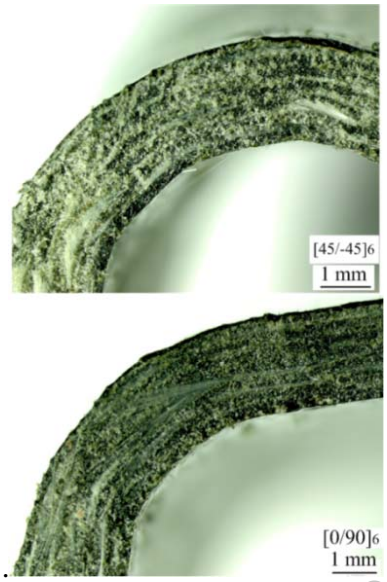

Fig. 2. Optic microscope images of 160°C press formed composite laminates

Geometrical Defects of Roll Forming Process

Spring back of the roll formed profiles increases linearly by increase of the roll forming angle. Conversely, spring back of sheet metals reduces by increase of the forming angle. This difference is because of the lack of plastic strains during forming of composite laminates. Indeed, elastic strains creation at elevated temperatures (low strength condition) and cooling down of the products to higher strength creates permanent strains. Spring back of the single stand roll formed profiles is presented in Fig. 3.

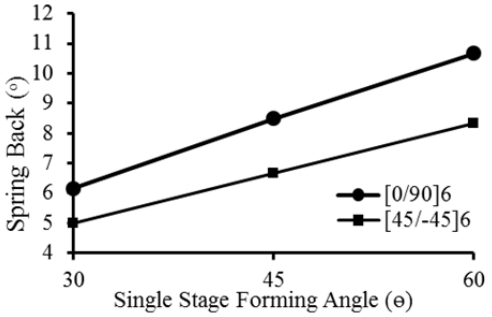

Fig. 3. Spring back of single stand roll formed profiles

Increase of forming angle also increases both flange waviness and warping defects. A permanent strain on the flanges of the formed profiles result in compressive stresses and these stresses cause warping and waviness (buckling) of the flange. Therefore, higher forming angles cause higher permanent strains and as a result, both defects increase. The effect of forming angles on these defects are shown in Fig. 4.

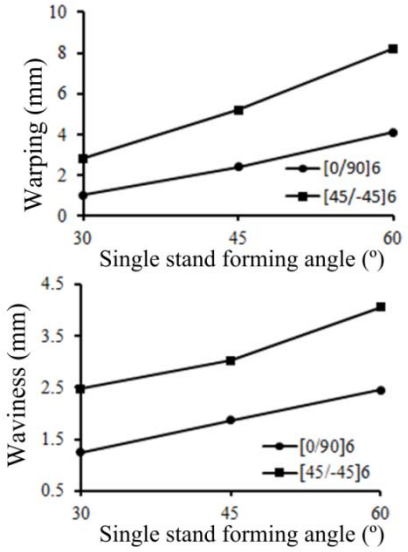

Fig. 4.Warping and waviness of single stand roll formed profiles

Warping and waviness defects in [45/-45] layup is higher than [0/90], while, its spring back is lower. This is due to the higher viscoelastic behavior of [45/-45] which results in higher permanent strains. For $[0/90]_6$ layup, multi stand roll forming defects are approximately equal to single stand roll forming of 30 degree. However, for $[-45/45]_6$ layup, defects in different stands are stacked and higher defects occur in multi stand roll forming.

4- Conclusion

In this article, formability and roll forming of PVC based composite laminates are studied. For this, composite laminates with $[-45/45]_6$ and $[0/90]_6$ layups are produced using film stacking procedure and then roll formed into channel section successfully. The main achievements of this paper are:

- Warping and waviness defects of [45/-45] layup are higher than [0/90] layup due to its higher viscoelasticity, while, spring back of [0/90] layup is higher.
- Permanent strains are created due to viscoelastic strains at elevated temperatures and cooling down to room temperature (higher stiffness), therefore, increase of forming angle results in higher elastic strains and spring backs.
- For multi stand roll forming of [0/90] layup, final stand has the dominant role on the defects, while, for [45/-45], defects of all stands are stacked.
- 160°C is the lowest proper temperature for forming of PVC based composite laminates.