ROLL FORMING OF ADVANCED THERMOPLASTIC COMPOSITE MATERIALS

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Abstract

Roll forming is one of the most efficient and pervasive metal working technologies for forming metallic sheet. Recently this technology has been successfully adapted for forming a variety of fiber reinforced thermoplastic composite materials. This paper offers a general overview of the roll forming operation as well as a summary of recent advances in the processing technology. An outline of the various application areas is also summarized with particular emphasis given to the potential cost savings that can be achieved using the roll forming method.

Background

The process of roll forming involves the gradual deformation of a sheet as it is fed through a series of matched rolls that are typically arranged in tandem. The operation is usually set up to run in a semi-continuous manner where the feed stock is supplied in coiled form. The line speeds and continuity that can be achieved coupled with the versatility and significant cost advantages of the operation have established it as one of the most productive and efficient metal working processes in existence. Additionally, ancillary operations such as notching, joining and cutting can also be performed on line. A typical roll forming line is shown in Figure 1. Common roll formed profiles are shown in Figure 2.

Figure 1. A typical roll forming line.

More recently, efforts have been made to adapt the processing technology for the purposes of forming fiber reinforced thermoplastic materials [1]. This has largely been driven by the unique processing characteristics of thermoplastic composites which lend themselves to such mass production techniques. These processing advantages combined with the increasingly competitive pricing, strong performance characteristics, and environmental tolerance see them well positioned to penetrate markets currently dominated by more traditional materials.

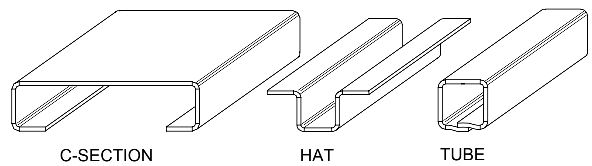

Figure 2. A selection of profiles that have been successfully roll formed.

The roll forming process

The entire roll forming operation, shown schematically in Figure 3, as it applies to the forming of thermoplastic composites can be considered in four parts: 1. Material Supply, 2. Heating 3. Consolidation and, 4. The forming operation. As with traditional roll forming, the feedstock is supplied on one or more coils. The actual form of the material may vary depending on the laminate required. Success has been achieved so far using a variety of material product forms including both woven fabric and unidirectional sheet. In practice any of the many and varied product forms currently available in coiled form may be used as feedstock. It is also possible to feed a braided preform (ie. sock) that affords the laminate fibers which are orientated away from the longitudinal axis of the profile.

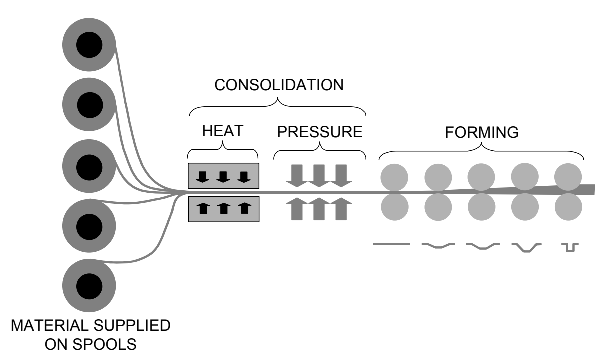

Figure 3. Schematic of roll forming operation.

As with other types of continuous operations, such as thermoplastic pultrusion, the method of heating depends largely on the volumetric throughput and speed at which it is being processed. Typical lines speeds so far are in the order of 30 ft/min although it is anticipated that this figure could be significantly increased using more aggressive heating methods than have been used so far. It must be noted however that any increase in line speed must consider the rate at which energy can be removed from the profile as it exits the process. Failure to adequately cool the part before it exits the roll mill results in poor shape conformance.

Continuous consolidation may be performed using one of a variety of methods including a double belt press or alternatively a series of compression rolls. As with any consolidation procedure the critical variables are time, temperature and pressure. Reducing any one of these necessitates the subsequent increase of one or both of the others. In terms of overall process speed, the consolidation stage generally imparts a limiting constraint.

The forming part itself is fundamentally the same to that of roll forming metallic sheet. The initially flat sheet is gradually deformed through a series of rolls that give the sheet a 3-dimensional form. Generally the forming sequence is depicted in the form of a flower pattern, an example of which is shown in Figure 4. As with metals the severity of forming, or rate of deformation (relative change in angle between one pass and the next), is an important design consideration. Studies by Henniger et al. [2] have determined an optimum forming sequence for a hat-section wherein the inter-ply shear is minimized for the web portion.

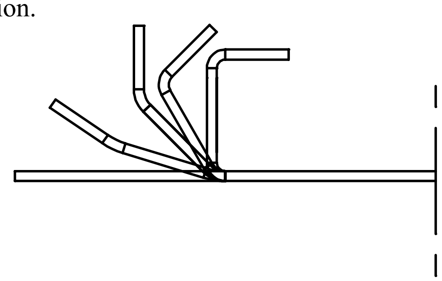

Figure 4. Flower sequence for C-section.

The previous discussion regarding the deformation of the sheet leads into a key point of difference between forming metallic sheet and thermoplastic composite materials – that is the deformation mechanisms involved in each case. Bend lines in metallic sheet are obtained by locally deforming the material in a plastic sense whereas for the fiber reinforced composites, the fibers act to constrain the material limiting any axial deformation to point of inextensibility. In addition the material softens when molten and behaves like a viscous fluid. These unique conditions give rise to highly anisotropic behavior and in the case of continuous fiber reinforced composites (woven or otherwise), as in Figures 5 and 6, the predominant mode of deformation becomes that of shear. In Figure 5, the deformation is shown in the plane of the sheet (intra-ply shear) and in Figure 6, the result of out-of-plane bending is shown in the form of a sheared edge. In practice, roll forming, like any other forming process, involves a combination of both intra-ply shear and inter-ply shear.

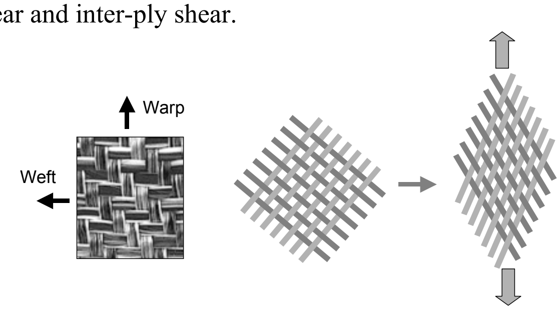

Figure 5. In plane shear deformation (trellising) of a woven preform.

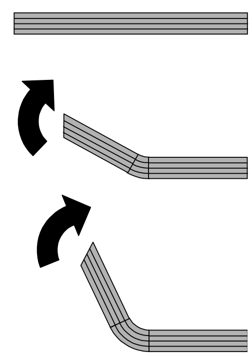

Figure 6. Out-of-plane bending giving rise to inter-ply shear.

As with metal roll forming, it is possible to induce longitudinal curvature and even form a fusion welded lap joint in a part online. Another technique which is worthy of note, and also used in pultrusion, involves extruding a polymeric resin over the profile to enhance it's overall appearance and durability.

While the basic concepts of roll forming thermoplastic composite materials have been introduced, a number of important aspects which remain proprietary in nature have been omitted.

Application Overview

Thermoplastic composites in general have found a great deal of applicability in the automotive sector where their low density and environmental tolerance work strongly in their favor. One area where they have demonstrated a measurable advantage is in energy management systems such as bumper beams and crush columns. A good example where significant weight savings and enhanced crashworthiness have been achieved is the BMW M3 front and rear bumper beams manufactured by AC.S and Jacob Composites GmbH (Germany). These particular beams, shown in Figure 7, are compression molded from Hexcel's GF/N6 Towflex® material and assembled using ultrasonic welding techniques.

Figure 7. The BMW M3 bumper beam system [3].

While composite materials have made strong inroads in the area of bumper beams, it is the high strength steel beams (typically roll formed) that dominate this market. Such beams offer strength (up to 180ksi) and stiffness that even the most elaborate and expensive composite systems would have difficulty competing with. The major drawback of these materials though, aside from difficulties in forming them, is the weight penalty they add to the vehicle. Alternatively, these types of structure could be roll formed from fiber reinforced thermoplastic materials at a much reduced weight. Advantages already acknowledged for thermoplastic composite bumper beams include the following [4]:

- Weight reduction
- High energy absorption efficiency
- Excellent stiffness/impact resistance trade-off
- High elasticity and ductility
- Recyclability
- Lower investment costs (compared with steel)

In addition to bumper beams, components such as crush columns, side intrusion beams and various other structural members could potentially be manufactured using the roll forming process.

The trucking industry, both light and heavy, is also an area where roll formed thermoplastic composite products are likely to find wide spread applicability. The trend nowadays is for purchasers of dry trailers in the heavy truck market to opt for "ballistic grade" thermoplastic composite liner material as opposed to traditional materials such as plywood. This is a result of the extremely high toughness and durability that flat reinforced thermoplastics panels offer. As the use of these materials grows there is likely to be a very real need for stiffening elements to support these wide panels. Tophat or Z-shaped sections could be used in this regard and fusion welded to the panel to provide additional strength and stiffness. Using sacrificial welding elements, as shown in Figure 8, eliminates the need for mechanical fasteners thereby preserving the structural integrity of the panel.

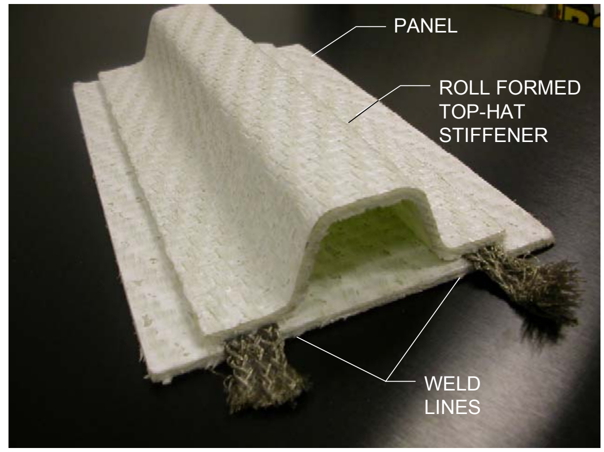

Figure 8. Fusion welding of a stiffener to a panel.

Cost savings

As mentioned at the outset, roll forming is one of the most efficient and cost effective methods of processing sheet steel. Scrap factors for roll forming are typically in the order of 3-5% as compared to 15-20% for stamped parts. As in metals, the material scrap factor for reinforced thermoplastic composites is expected to be relatively low compared to rival process where much time and cost is associated with trimming excess material to achieve the net shape.

Additionally, the tooling costs for roll forming thermoplastic composite materials are substantially lower than for compression molded processes. The rolls themselves may be manufactured from a variety of different materials including non-metallic materials that assist with minimizing the heat loss from the part as it is formed. Alternatively, traditional steel or aluminum rolls can be employed although no special hardening treatment is required.

While so far the process has been designed for use on a conventional roll mill, the long term capital costs associated with the forming equipment will be much less than for a standard machine. This is due to the low forming loads that are practically negligible when compared to those encountered in a typical metal roll forming operation. This paves the way for light weight, custom designed equipment that will be easily transportable and highly versatile.

Summary

The ability to process thermoplastic composite materials economically is the key to their long term viability in the automotive sector. Roll forming is one such method that offers the very real potential for mass production of components such as bumper beams, crush columns and various other structural parts.

References

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