PUSHING THE BOUNDARIES OF CARBON FIBRE SHEET MOULDING COMPOUNDS: APPLICATION TO THICK AUTOMOTIVE COMPONENTS

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ABSTRACT

Carbon Fibre Sheet Moulding Compounds (CF-SMCs) are carbon tow based composites; SMC components are obtained by compression moulding of thin prepreg sheets. Automotive industries use these materials mainly for thin panels; manufacturing of SMC thick-walled parts remains challenging and unconventional, although it could contribute to significant weight reduction. To expand the possible applications of CF-SMC, a 15 mm thick automotive part was here manufactured and tested in bending. The charge placement inside the mould proved to be a key factor for the component mechanical performance. Effects of moulding temperature, pressure and cooling rate were hidden by the high material variability.

1. INTRODUCTION

Carbon Fibre Sheet Moulding Compounds (CF-SMCs) are composite materials made of chopped carbon fibre tows dispersed in a partially cured thermosetting resin. SMCs are very suitable for the automotive industry [1]. The compression moulding process, in facts, allows the fast manufacturing and high processability of short fibres composites, while the long tows ensure higher mechanical properties.

For those reasons, SMCs are the best candidates to replace metals in chassis components. However, their use is still limited to thin panels, since the prepreg material is in the form of sheets. Therefore, to the best of our knowledge, the feasibility of thick SMC parts has not been investigated yet. Compression moulding of such components remains a challenging and unconventional process, and moulding parameters' influence on parts' performance have never been investigated. First of all, residual stresses may arise when warpage is prevented by a thick-walled design [2]. Moulding temperature and cooling rates can thus affect the mechanical performance of thick parts. Moulding pressure can also play a role, as it usually helps to reduce voids and porosity in general. Finally, complex 3D geometries can facilitate the formation of weld lines.

In this work, a 15 mm thick component, whose design is derived from an actual chassis part, is compression moulded. The first challenge encountered was the search for an optimal placement of the prepregs inside the mould (charge pattern). Given its bulkiness, a complete weld line-free part was not achievable. Four different charge patterns were thus considered. Bending tests were used in the identification of the pattern resulting in the highest mechanical performance. This pattern was then used to investigate the effects of moulding parameters, namely temperature, pressure and cooling rate.

2. MATERIAL AND METHODS

The material considered in this study is provided by Mitsubishi Chemical Corporation under the name of Pyrofil^{TM} STR120N31. It is a carbon/vinyl ester SMC provided in partially cured sheets. Data coming from the datasheets [3,4] for both carbon fibre strands and overall composites are reported in Table 1 and Table 2 respectively. Moreover, recommended moulding conditions for thin components are also reported in Table 3.

Table 1: Properties of the carbon fibre strands from [3].

Tensile strength	Tensile modulus	Failure strain	Filament count	Fibre diameter	Dimensions (mm) *(length* x *width* x *thickness)*
4900 MPa	240 GPa	2.0%	15k	6.8 μm	25.4 x 8 x 0.115

Table 2: Properties of the SMC composite from [4].

Fibre content	Density	Tensile strength	Tensile modulus
53% (w/w)	1.46 g/cm^3	150 MPa	33 GPa

Table 3: SMC moulding conditions recommended by [4] for thin components.

Moulding pressure	Moulding temperature	Cure time
5 – 10 MPa	140°C	2 – 5 mins

The component object of this work is shown in Fig. 1. It features a wall thickness of 15 mm, and also includes two steel inserts. It was moulded in a Fontjine Holland press. The press was displacement controlled, so a precise control over the moulding pressure was not possible.

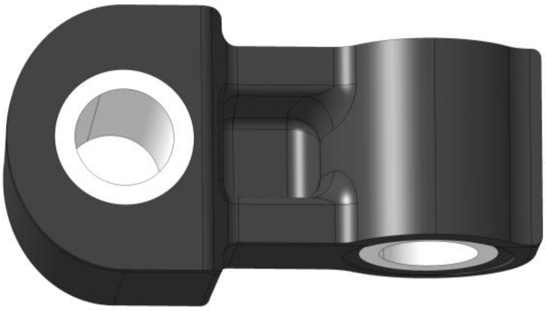


Fig. 1: Geometry demonstrator, derived from an actual chassis part.

At first, an evaluation on the best Charge Pattern (CP) was performed. Four different CPs were considered, all described in Fig. 2, as consecutive placement steps. For all of them, the target charge weight was 670 g ± 8 g and moulding conditions followed those of Table 3. They are here briefly described (variation of the number of plies was needed to ensure a consistent weight for all CPs):

- CP-A: five plies were wrapped around each insert, and then 20-24 more stacked in the middle. Eventually, few other plies were stacked on top to reach target weight.
- CP-B: five plies were wrapped around the left hand-side insert. Around the right hand-side one, five plies were wrapped around in a U-shaped fashion. 15-19 plies were stacked in the middle.

- CP-C: five plies were wrapped around the left hand-side insert in a C-shaped fashion, with longer upper edge. Then, 27-29 plies were cut following the net-shape of the mould, and then stacked on the right-hand side of the mould
- CP-D: five plies were wrapped around the left-hand side insert as done in CP-C and around the right hand size insert as done in CP-B. 15-19 plies were then stacked in the middle.

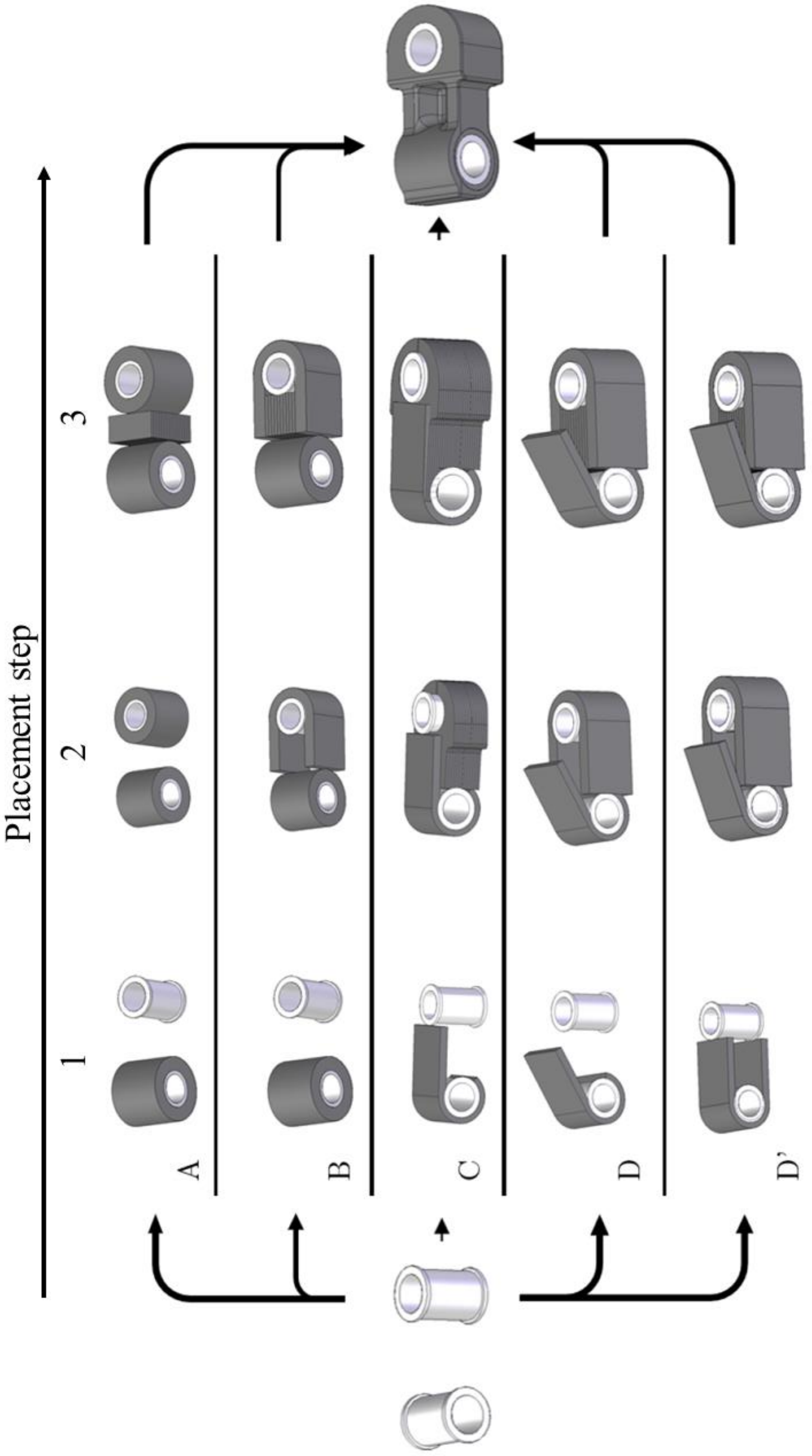


Fig. 2: Visual representation of the different charge patterns (CPs)

In addition to that, a tentative improvement of CP-D led to a CP-D’:

- CP-D’: five plies are wrapped in a U-shaped fashion around each insert, instead of only the right hand-side one. 15-19 plies are stacked in the middle.

CP-D’ was used, in a second investigation, to assess the effects of moulding parameters. The different values of the parameters varied during mouldings are reported in Table 4. For the cooling of the parts, two methods were used. The first is to simply cool the part in open air; the second one was to put it in an 80°C oven for 24 hours after demoulding, and then let it cool in open air. This method will be referred in the rest of the paper as “controlled”. Following a factorial design approach [5], with two replicates per combination (temperature – pressure – cooling), a total of 16 parts were tested.

Table 4: Moulding parameters varied for the investigation on their effects on the final mechanical properties

	Maximum moulding force (A)	Moulding temperature (B)	Cooling method (C)
Level 1	20000 kgf ± 5000 kgf	130°C	Open air
Level 2	80000 kgf ± 20000 kgf	140°C	*Controlled*

The evaluation of the best charge pattern first, and of the influence of the moulding parameters second, was done via component bending tests. The boundary conditions applied to the part are shown in Fig. 3. The maximum value of the load during testing is the bending strength of the part. Displacement rate was set to 1 mm/min, while load cell capacity was 250 kN.

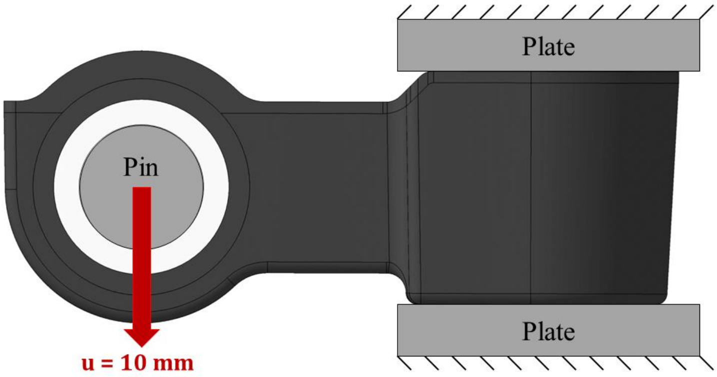


Fig. 3. Boundary conditions during bending tests of the component

3. RESULTS AND DISCUSSION

3.1 Charge pattern investigation and discussion

Fig. 4 shows the results of the bending tests of the parts moulded with different CPs in terms of bending strength vs displacement at failure. CP-A performed the worst, with an average failure load of 6.6 kN. CP-D perform the best, with an average strength of 28.2 kN.

An important difference between SMC thin panels or bulky parts lies in the nature of the weld lines. In thin shapes, the weld lines are well approximated by the concept of *line*; in 3D complex shapes, instead, the melt fronts actually meet in a surface, thus constituting a weld *surface* or *area*. The formation of these weld surfaces is believed to be the main reason behind the different performance of each CP. CP-A leads to the creation of two weld surfaces, while CP-B only of one. This already shows an improvement of the 102 % of the bending strength between the two CPs. As an additional proof of a weld surface dominated failure, CP-B parts all failed consistently in the location of the only weld surface, while CP-A parts failed in between the two weld surfaces.

CP-C and CP-D showed even higher mechanical performance, with a bending strength increase of 181% and 325% compared to CP-A, respectively. In both cases, the weld surface was spread within the volume of the part, and there were no weld cross sections. This is probably the cause of the higher failure load observed with those patterns. The failure location of CP-C and CP-D parts was variable. This proves that the failure was not dominated by a single large defect, but rather by the intrinsic SMC variability. Small flow-induced defects (like cracks and voids) have been indeed reported not to affect the failure behaviour this material.

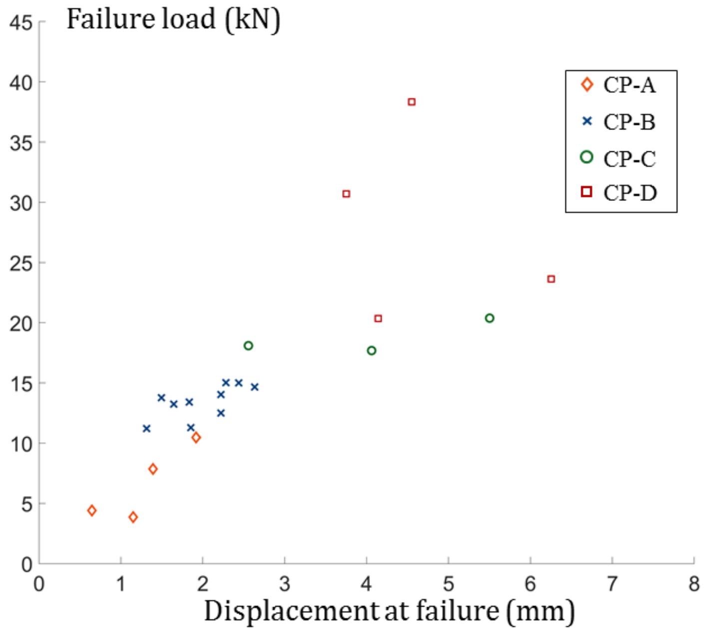
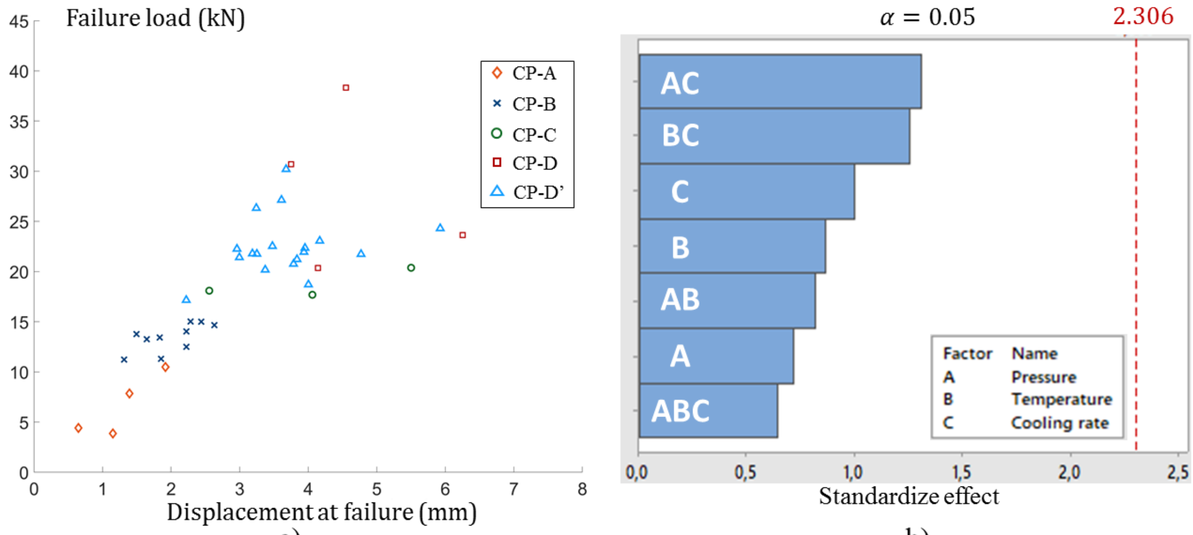


Fig. 4: Failure load against displacement at failure of the component bending tests for the charge pattern investigation.

3.2 Effects of moulding parameters

The results of the moulding parameters investigations are shown in Fig. 5. CP-D’ parts had comparable bending strength as the CP-D ones (see Fig. 5-a), thus out-performing all other patterns.

As suggested by [5], each configuration is called using the capital letter of the parameters at level 2 (see Table 4); for example, AB indicates high pressure, high temperature and open air cooling. The low pressure, low temperature and open air cooling is the reference against which the effects of the parameters variation will be compared. The Pareto chart in Fig. 5-b, shows how the standardized effects of the parameters variation is far below the threshold of 2.306 identified with a two tailed student-T distribution. This means that varying the considered parameters has no significant influence on the overall strength of the component.



a)

b)

Fig. 5: Results of the investigation on moulding parameters influence: a) failure load against displacement at failure and b) Pareto chart of the standardize effects of moulding parameters variation.

4. CONCLUSIONS

In this study, the feasibility of a thick compression moulded SMC component was evaluated. The part object of this study has a wall thickness of 15 mm. To the best of our knowledge, no such thickness has ever been reported in the scientific literature or in any industrial application for CF-SMC parts.

In a first study, four different charge patterns were compression moulded. The presence and location of weld surfaces impacted significantly the strength of the component. Breaking and spreading those weld surfaces in different areas of the component lead to an increase of strength of up to 325%. The difference between weld lines in thin panels and weld surfaces in 3D complex shapes was also discussed: weld surfaces can be broken and spread in perpendicular planes to avoid weld cross-sections, as done in CP-D. The compression moulding of SMC 3D complex parts can be carefully optimised to increase the final parts mechanical performance.

The charge pattern D' was then used to evaluate effects of moulding parameters. Parameters variation involved temperature (130°C or 140°C), pressure (high or low) and cooling rate (open air or slower rate). However, none of those parameters significantly affected the final strength of the component. Since CF-SMC is a highly heterogeneous material [6], the effects of those parameters are likely to be hidden by the material variability.

5. ACKNOWLEDGMENTS

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