INFLUENCE OF PROCESSING TEMPERATURES ON THE DEFLECTION OF HYBRID-METAL-CARBON COMPOSITES MADE BY RESIN TRANSFER MOULDING

Patrick Hergan[1], Julia Beter[1], Steffen Stelzer[2], Ewald Fauster[1] and Ralf Schledjewski[1]

[1] Otto Glöckel-Strasse 2, A-8700 Leoben, Austria, Department Polymer Engineering and Science, Processing of Composites Group, patrick.hergan@unileoben.ac.at, julia.beter@unileoben.ac.at, ewald.fauster@unileoben.ac.at, ralf.schledjewski@unileoben.ac.at, http://kunststofftechnik.at/de/5534/

[2] Otto Glöckel-Strasse 2, A-8700 Leoben, Austria, Department Polymer Engineering and Science, Chair of Materials Science and Testing of Polymers, steffen.stelzer@unileoben.ac.at, http://kunststofftechnik.at/de/5543/

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ABSTRACT

This paper shows the impact of resin pre-heating temperature and mould temperature on the deformation of hybrid metal CFRP plates manufactured through a single-step resin transfer moulding process. A design of experiment study was carried out and the final plate deformation was measured by a laser based measuring system. The study shows the interaction between the process temperatures on the final part geometry. Strategies to reduce the temperature induced deformations and stresses will be discussed.

1 INTRODUCTION

New part design often hides challenges for the used materials. Sometimes common materials can't fulfil the requirements of stiffness, weight and impact resistance. Therefore, a new material cluster was developed: The so-called hybrids. These materials are composed of different common materials but their properties are combining in such a way that they can fulfil requirements the single materials can't [1]. But as everyone knows nearly no solution comes only with positive aspects. Of course there are also some negative aspects which occur when two materials with different properties are combined. Composite materials itself are already hybrids with, for instance epoxy resin and carbon fibres as constituents. The production step of composites is directly linked to the final mechanical properties of the part. There are many processing techniques known for manufacturing parts but only a few are suitable for producing a high annual output.

Resin transfer moulding (RTM) is a well-known technique to produce fibre reinforced plastics (FRP) [2]. Especially the automotive industry is using this technique to produce structural parts for upper class and sport cars [3]. As usual chassis are mainly made out of metal, connection points between FRP and steel or alumina occur if hybrid chassis are built [4]. The two different materials can be fixed to each other by using different methods [5,6]. In order not to damage the composite by drilling holes to insert screws or rivets a solution using adhesives is reasonable [7,8]. The procedure to connect the two materials to each other results in an additional step during production. This leads to additional costs. To avoid this additional step the production step of the composite part itself can be used as gluing step at the same time [9]. Therefore, a special resin system can be used which works as matrix for the FRP and as adhesive between the metal and the FRP. This leads to the production of a hybrid-metal-carbon composite in one single step process. Figure 1 shows the principle of the RTM process for hybrid-carbon-composites. The carbon fabric needs to be cut in the appropriate shape before it can be preformed. In the following step the metal part and the preform are placed in the mould. After closing the mould the resin can be injected. While curing, the resin builds up the interface towards the metal. Afterwards the hybrid part can be demoulded. The two materials are fixed together due to the adhesive behaviour of the resin.

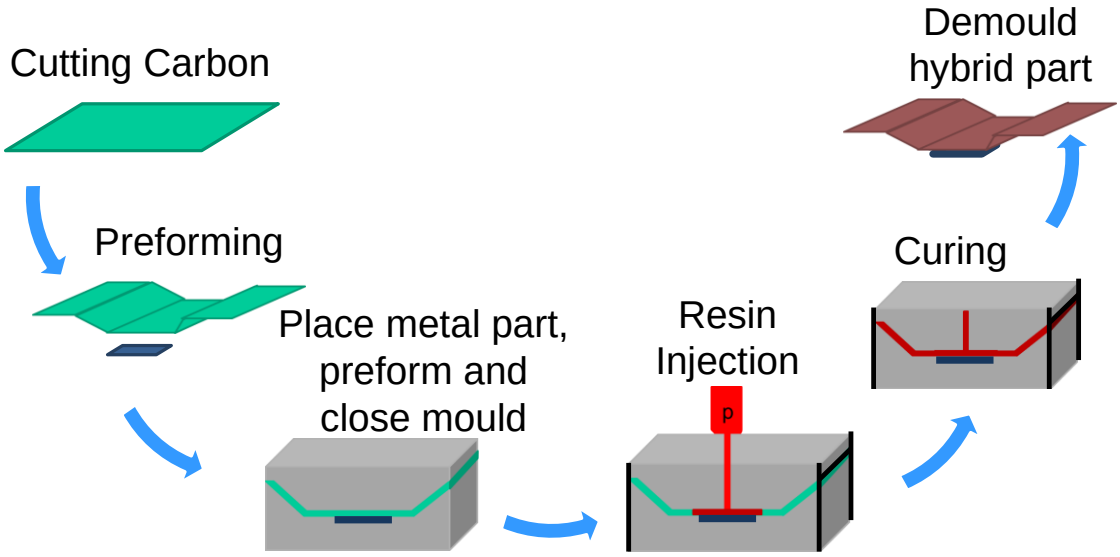

Figure 1: Principle of the RTM process for metal-carbon-hybrid parts.

This procedure is advantageous in respect to save the step of gluing but it also hides some challenges. On the one hand a proper resin system needs to be developed which has good adhesive properties to the metal part but on the other hand the properties of the two constituents (i.e. metal and CFRP) need to be considered in detail for properly managing the manufacturing process. It is well known that the thermal expansion coefficients of these two materials are quite different [10]. This leads to thermal induced stresses when a temperature change occurs. These stresses can become so high that they lead to deformation or debonding [11]. To reduce the viscosity of the resin it must be heated before the injection. This helps to prevent high injection pressures and long filling times. Furthermore the mould must be heated to a certain temperature to reach a high curing degree within short times. So when the final part gets demoulded and cools down to ambient temperature the elevated temperatures, which are part of the RTM process itself, are striking and automatically lead to temperature induced residual stresses.

2 EXPERIMENTAL

This study was carried out to learn more about the influence of the processing temperatures on the final part geometry. Therefore a design of experiments (DoE) study was carried out. The variables in this study were the pre-heating temperature of the resin and the temperature of the mould.

2.1 Material

The specimens were plates with dimensions of 270 x 270 x 4 mm. Two millimetres of the plates were made out of steel and the other two millimetres where made out of six sheets of different fibre fabrics. Table 1 shows the materials used for the production of the specimens.

Material	Specification	Supplier		Areal Weight	Symbol
Metal	Steel 1.0548 HC340LA	TK	–	–	A
Carbon Fibres	Style 423-1, 6K	ECC	[g/m²]	253	B
Carbon Fibres	650SA4, 12K HS	CHOMARAT	[g/m²]	670	C
Glass Fibres	microlith ST 3022	Johns Manville Corp.	[g/m²]	27	D
Resin	Epinal IR 77.55-A1	bto-epoxy	–	–	–
Curing Agent	Epinal IH 77.55-B1	bto-epoxy	–	–	–

Table 1: Used materials for the production of the hybrid-metal-carbon-composite.

As one can see there are three different fibre materials used. The layup for the preform is shown in Figure 2 the symbols A, B, C and D are referred to the materials shown in Table 1.

Figure 2: Stack layup of the hybrid metal carbon composite plates with A) steel HC340LA, B) Style 423-1, 6K carbon fabric, C) 650SA4, 12K carbon fabric and D) microlith ST 3022 glass fabric.

The steel plate is sand-blasted on the side which is next to the fibres to facilitate better bonding. The thin glass fibre fleece as outer layer of the composite was used to prevent contact induced corrosion between the steel and the carbon. The composite stack itself was designed symmetric to prevent inner stresses but due to the bonded metal on the lower side the hybrid plate truly doesn't show symmetric characteristics.

2.2 Experimental Setup

For the DoE study the temperature of the resin and the temperature of the mould were varied on two stages. The temperature of the resin was varied between 65°C and 75°C. This range was set due to the specific properties of the resin. Below 65°C the resin has a too high viscosity which leads to problems during the mould filling step. On the other hand the used heating unit was only able to guarantee a uniform heat distribution up to 80°C.

The mould temperature was varied between 100°C and 120°C. The proposed curing cycle for the used resin system is 25 minutes at 100°C. To ensure a high curing degree the curing time was kept constant also for a mould temperature of 120°C. To prevent the epoxy from thermal degradation the mould temperature wasn't raised to higher temperatures. Table 2 shows the four different temperature settings of the DoE study. To ensure statistics all settings were repeated six times and of course randomized.

Set Nr.		Resin Temperature	Mould Temperature
#1	[°C]	65	100
#2	[°C]	65	120
#3	[°C]	75	100
#4	[°C]	75	120

Table 2: Used temperatures for the different settings of the DoE study.

The mould used for the experiments is made out of steel and heated by a water-based heating system. The cavity is 270 x 270 x 4 mm and uses a line distributer for the resin in the front. The mould is mounted at a Langzauner LZT-OK-80-SO press and a closing force of 300 kN was applied during injection and curing. The resin was injected by a Tartler Nodopur VS- 2K injection unit.

After demoulding, the part was cooled down to ambient temperature (23°C) and its deflection was measured with a laser triangulation sensor. The sensor scanned the surface with a grid of 60 x 60 mm while it was taking a measurement every millimetre. To prevent the measurement of edge effects a frame of 15 mm to the edge was not measured. Three of the corners were fixed while one was able to move vertical.

3 RESULTS

As mentioned before a total of 24 plates were manufactured and measured.

Figure **3** shows a cool plate which was manufactured with 100°C mould temperature and 65°C resin temperature.

Figure 3: Picture of a hybrid metal carbon plate manufacture with Set #1.

The maximum deflection of the plate was taken as the deflection value for the DoE study. Figure 4 shows the measurement data responding to the plate shown in Figure 3. A second order surface equation was fit to the measurement points and indicates the amount of deflection.

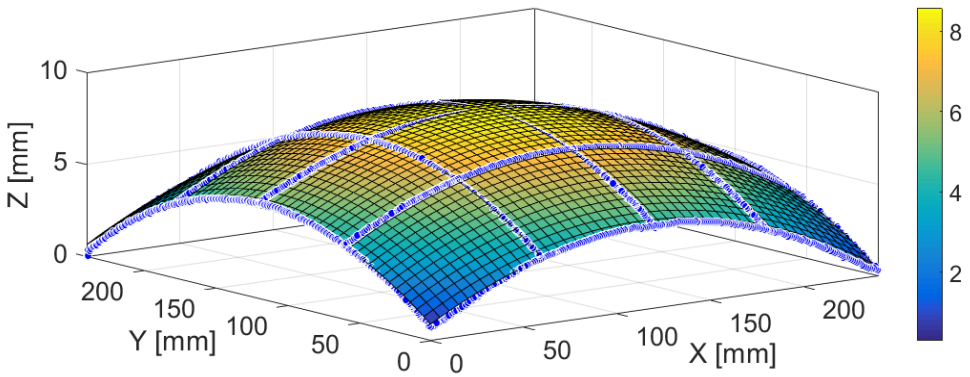

Figure 4: Measurement data of a hybrid metal carbon plate manufactured with Set #1.

3.1 Statistical analysis

To analyse the main effects and find out about their significance the statistics tool Minitab 17 was used and main effects plots of the deflection caused by resin temperature and mould temperature were made. The results are shown in Figure 5. It can be seen that the resin temperature has rather no significant effect on the maximum deflection while the mould temperature shows a strong impact. Also the standard deviation of the maximum deflection by the resin temperature is much higher compared to the standard deviation of the deflection caused by the mould temperature.

This can clearly be addressed to the different thermal expansion coefficients of the steel and the composite. The thermal expansion coefficient of the steel plate was measured to be 10*10E-6 1/K while the in-plane thermal expansion coefficient of the composite was measured to be 3.5*10E-6 1/K [12]. The deviation of 6.5*10E-6 1/K leads to a calculated difference of elongation between the metal part and composite part at the hybrid plate by cooling down from 100°C to 23°C of 1.35 millimetre. This leads to the observed bulging of the plate.

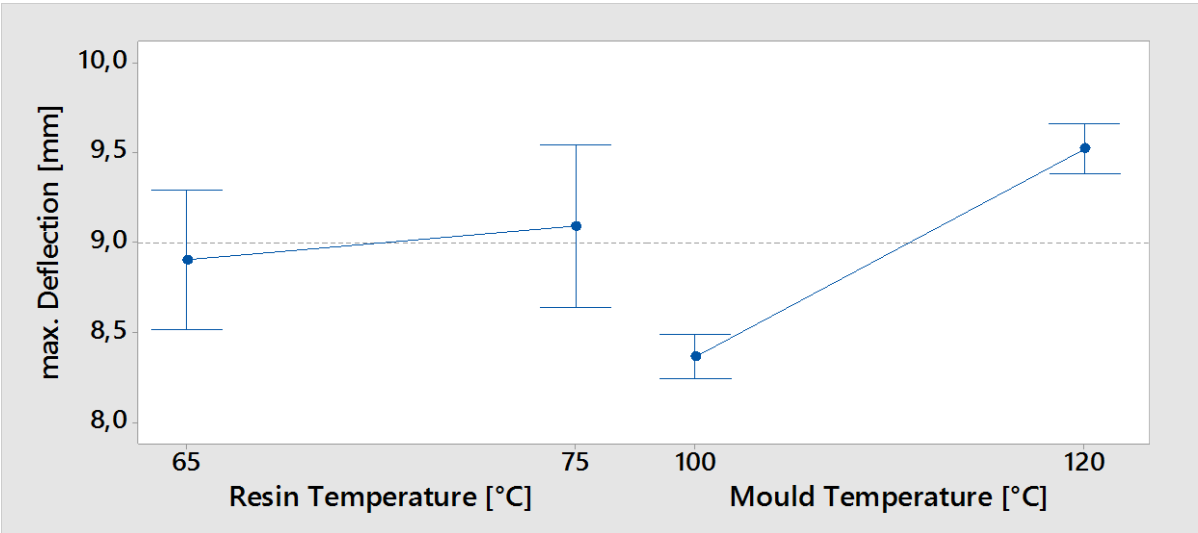

Figure 5: Main effects of maximum deflection by resin temperature and mould temperature.

To find out if there are some interactions between the resin temperature and the mould temperature which effects the maximum deflection of the plate an interaction plot was made. In Figure 6 it can be seen that the interaction between these two parameters is not significant. However, it is interesting that the resin temperature seems to have a higer impact on the mould deflection at high mould temperatures. This can be linked to the energy needed to start the crosslinking reaction within the resin system. With higher mould and resin temperatures, this energy level can be reached faster and therefore, the gelation of the resin system starts at an earlier stage. This can lead to gelation effects of the resin system at direct contact points towards the steel plate and the mould surface. It needs to be stated that stresses only can built up in a non-liquid state so this is what happens in the edge regions of the composite.

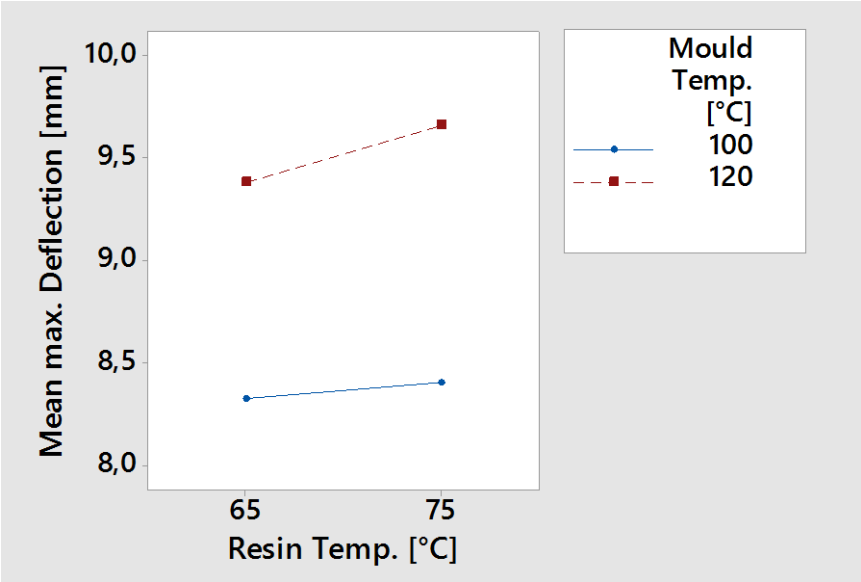

Figure 6: Interaction plot for maximum deflection.

4 CONCLUSION

The study presented in this work shows the link between deflection of metal-carbon composites and the processing temperatures. As a result of the DoE study it was shown, that the mould temperature has a highly significant impact on the deflection. This is directly linked to the difference between the thermal expansion coefficent of the materials used in the hybrid. It was observed that the resin temperature might have a low but not significant influence on the deflection. This influence is raising with increasing mould temperature. This can be linked to fast gelation of the resin system in border regions.

To keep the deflection of the part as low as possible a low temperature of the mould is recommended. In order of the curing behaviour of thermoset resins this is not always possible and a too low curing temperature may leed to bad mechanical properties and a low glas transition temperature of the final part. Therfore, other processing parameters such as injection pressure and mass flow while filling might be used to optimize the deflection behaviour. Nevertheless the deflection is not the only important parameter which must be observed. Also mechanical parameters such as the bending modulus and interface strength need to be taken into account to describe the part quality. Due to economical reasons, processing times should be kept short and therefore, the filling and curing times need to be reduced. The listed control and quality parameters will be observed in an advanced and extended study.

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