CHARACTERIZATION OF DISSIMILAR JOINTS OF ADVANCED LIGHTWEIGHT MATERIALS

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Abstract

Weight reduction by employing lighter alloys, composites, or stronger materials of a smaller cross in novel, multi-material design sections is increasingly becoming the key to success in nowadays material engineering. This is particularly representative for aircraft, automotive and train structures where energy efficiency is essential in order to minimize operating costs. In recent years, tremendous progress has been made in the technology of lightweight materials, in the case of both metals and composites. However, some products require the combination of both groups of these materials, while at the same time achieving a negligible decrease of achieved synergic properties. Therefore, the development of a suitable joining method using different composites is indispensable. For the manufacturing of the metal matrix composites and lightweight alloys specimens, the advanced Gas Pressure Infiltration method has been used. The metal/CFRP multi structural composite has been prototyped by the adapted Resin Transfer Moulding (RTM) method. This paper presents an experimental study of the novel joints of dissimilar materials, such as Carbon Fibre Reinforced Polymers (CFRP), lightweight metal alloys, and Metal Matrix Composites (MMC), manufactured by the help of adequate methods. This research focuses on the advantages and development of the joining of dissimilar advanced lightweight materials. The specific objective of this paper is to evaluate the quality and durability of joints between CFRP and metal alloy/MMC. There are reasonable evidences to conclude that the durability of the joints being investigated strongly depends on the arrangement of used materials, and type of components used.

Keywords:
Carbon fibre reinforced plastics, gas pressure infiltration, resin transfer moulding, metal inserts

1. INTRODUCTION

Carbon Fibre Reinforced Polymer (CFRP) composites are appropriate for use in a wide range of engineering fields because of their high strength-to-weight and stiffness-to-weight ratios, corrosion resistance and potentially high durability characterization [1]. Today, light resin transfer moulding, resin transfer moulding, hand lay-up and Vacuum Aided Resin Infiltration (VARI) (among other manufacturing processes) can be successfully utilized. Laminates manufactured by the help of RTM process are characterized by particularly high fibre content, low voids ratio, and a superior surface finish [2]. The added benefit is that the resin transfer through closed mould allows to control of fumes, which leads to the improvement of health and safety. The CFRP is a lightweight composite applied mainly in aerospace and automotive industries [3]. Therefore, it is extremely important to investigate the joining method of this continuously developing material with commonly used casting alloys [4,5]. Nowadays, more emphasis is continuously placed on the investigations on the field of novel joining methods between dissimilar materials [6-8].

2. PRINCIPLES OF MANUFACTURING

The laminates used in this experiment were manufactured using the vacuum-assisted, closed-mould RTM process. An eight layer of reinforcement textiles were placed into mould.
This process reveals the following benefits [9]:

- superior laminate surface quality;
- ability to manufacture large, complex shapes;
- integration of ribs, cores and inserts;
- wide range of resin and reinforcement systems;
- controllable fibre volume fraction.

Most RTM applications use two-part epoxy formulation, mixed before injection and preheated to 40°C. The mixture has been placed in vacuum chamber and degassed. Within the infiltration process the pressure and vacuum test were conducted. The mould was preheated to 40°C to maintain the resin viscosity. The infiltration starts using vacuum, and stops in the 5 bar pressure. To achieve sufficient infiltration quality, vacuum was indispensable. After the infiltration laminate was cured at 70°C for 10h.

Inserts for laminated plate has been manufactured with the aid of an advanced gas pressure infiltration technique particularly favourable for metal matrix composites manufacturing [3,5]. Designed technique consists of a moulding system for the manufacturing of plate shape (150 mm x 65 mm x 2 mm) specimens. The main principle of this method is an applied-vacuum allowing reducing the porosities during the infiltration of the preform.

3. SPECIMEN CHARACTERIZATION

To perform quasi-static tensile test, specimens (dimensions: 250 mm in length x 25 mm in width x 4.5 mm in thickness) of each laminate group (CFRP_226D-MMC; CFRP_AZ61; CFRP_226D) has been used. Figure 1 and 2 show the specimen geometry and illustrates the metal inserts in cut samples.

![Fig. 1 Geometry of specimen](image1.jpg)

![Fig. 2 Specimens with the integrated metal matrix composite inserts](image2.jpg)
4. QUALITY ASSESSMENT

After infiltration, the quality assessment of the plate by the help of computed tomography and ultrasound techniques has been done. The results reveal that the RTM process in adapted conditions provide an appropriate infiltration (Fig. 3). Low amount of voids and discontinuities between reinforcement and matrix have been observed.

![Fig.3 Results of quality assessment: CT (left); ultrasonic sonography (right)](image)

Moreover, to reveal the sufficient adhesion the scanning microscopy investigation with the focus on the contact surface between metal insert and polymer based composite has been done (Fig. 4).

![Fig. 4 Microstructural quality investigation: contact surface between Metal Matrix Composite (226D alloy/CF) and CFRP](image)

Microscopic analysis shows low amount of voids in the vicinity of CFRP and MMC contact boundary. Regarding to this fact there were reasonable presumptions that infiltration and embedding process have been performed appropriate.
5. TENSILE TEST
To reveal the adhesive properties of all joints the tensile test has been carried out according to the DIN EN ISO 527 standard using the universal machine Zwick/Roell 1465 with a 50N preload, at a crosshead speed of 2 mm/min. Moreover, to investigate the areas that are the most vulnerable to fracturing the tensile test has been aided by high resolution measuring system ARAMIS allowing exact monitoring of the deformation stage of hybrid joints. The tensile test results of the manufactured samples and an example of ARAMIS measurement have been shown in Figure 5 and 6.

![Tensile test results](image1)

**Fig.5** Tensile test results: maximum tensile strength (left); representative strenght-strain curves (right)

Curves of tensile tests with embedded inserts exhibit a characteric similar range of increased elongation at stable stress rate (plateau), what may be caused by failures of adhesion between embedded inserts and polymer matrix. This range reveals the strength of conection between these materials and correspondens with delamination shown in the fracture analysis.

![ARAMIS measurement results](image2)

![Fracture analysis](image3)

**Fig. 6** Example of ARAMIS measurement system results.

The ARAMIS aided measurement (Fig.6) results show the decrease of the strength of composites in the contact vicinity between metal matrix inserts and epoxy resin composite. This aspect reveal the necessity of further research on the surface preparation to receive adapted multi-material conection capable of working in demanding loading conditions.
6.  **FRACTURE ANALYSIS**

For exact investigation of the adhesive joint properties, failure mechanisms and fracturing phenomena of tested specimens the microscopic analysis by the help of stereoscopic optic microscope and scanning electron microscope has been done (Fig. 7 and 8).

![Fig. 7 Microscopic pictures of fracture shape: 200x (left); 150 x (right)](image)

The pictures of fracture by stereoscopic microscope reveal that the shear stresses between the inserts and CFRP play main role in the failure mechanisms and causes the delamination of the specimens. Cracks has been generated form the corners of the insert and propagated along the CF-layers finishing in consequence as delamination of specimens.

![Fig. 8 Fracture in the metal matrix composite: 600x (left); 80x (right)](image)

Figures 8 show the microsection which was found on the joint between the metal insert and the CFRP. They reveal high dependency between fibre arrangement and strength of multimaterial joint. The matrix can be seen ripped off from its reinforcement, contributing to a failure mode known as debonding. A lack of tear between metal and the CFRP breaking in the direction of the carbon fibre was also observed.

In Figure 8 (left), it can be observed that the sample appears to be damaged during the process of ripping off from the carbon fibre reinforcement out of the matrix. This aspect is an effect of further delamination.
Figure 8 (right) illustrates a metal reside at a joint boundary of a metal insert and CFRP. Therefore, it can be concluded that after optimal surface preparation both dissimilar materials can be successfully joined.

7. SUMMARY AND CONCLUSIONS

In this paper investigations of joints of dissimilar materials has been performed. Three different metal inserts has been used and inlaid into CFRP structure during RTM process. Quality and strength of joints between lightweight metal alloys and CFRP as well as between MMC’s and CFRP have been investigated. The achieved results reveals, that selected and adapted manufacturing method is adequate to fabricate joints with satisfying quality and required durability. Computed tomography and ultrasonic scans revealed that there is low amount of voids and defects formed in the structure of investigated material during manufacturing process, what has been confirmed by microscopic analysis. In the cross-sections of investigated joints low amount of discontinuities has been observed what indicates the favourable connection between joined structures. Strength-strain curves reveal a specific range (plateau) occurred only in samples with metal inserts, revealing the strength of multimaterial-connection. The highest tensile result has been achieved for sample with AZ61-insert what predestine this material for further investigations.

The performed studies have led to the following conclusions:

- RTM process is an adequate process for manufacturing high quality joints of dissimilar materials.
- Mg-alloy based inserts have favourable adhesion to CFRP in the multi-material connection.
- Mechanical tests reveal, that multi-material connection is capable to bear the load only to specific elongation stress range in which the shearing stresses contributes to delamination of joint.
- Further investigations on the surface preparation of metal inserts are indispensable [10].

LITERATURE

[9] HSIAO K.T., Vacuum assisted resin transfer molding (VARTM) in polymer matrix composites, Manufacturing Techniques for Polymer Composites (PMCs), 2012, p. 310–347