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Production and Characterization of Carbon-Kevlar-Aramid Reinforced Layer Composites with VARTM Method

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ABSTRACT

In this study, laminated composite materials are produced by Vacuum Assisted Resin Transfer Molding (VARTM) Method. Three different reinforcement materials (carbon, kevlar and aramid) are used in the production phase. Tensile test is applied to the samples after the production and in the light of SEM images; fractured surfaces of the samples and their results are evaluated.

It is obvious that the mechanical properties of carbon fiber reinforced samples yield better results.

Keywords: Kevlar, Carbon, Aramid Reinforcement, VARTM Method, Composite.

1. INTRODUCTION

Kevlar reinforcement material is widely used in composite production area thanks to its high impact resistance, high wear resistance and fatigue strength, high chemical resistance and hardness properties. In particular, it is used for carbon aramid reinforced fabric production extensively [1]. Composite materials are designed for high performance applications and their properties are designed according to specific purposes and desired functions [2]. Usage areas of composites are wide and expanding day by day [3]. Vacuum infusion method works with the principle of the progression of the resin in vacuumed media. In this method, are it is aimed to manufacture the product without touching it after production preparation is completed. It is important that the resin impregnated with the materials has an appropriate viscosity. Where narrow gap measurements and long flow paths are involved, the resin needs to be absorbed into its fibers to be strengthened as soon as possible. Generally epoxy, polyester and vinyl ester resins are used. The infusion (transfer) method consists of four parts: vacuum pump, vacuum tank (resin collection tank), mold and resin bucket. The connections and shapes of these four parts may change, but the overall system is always the same [4].

Gu et al. have produced aramid fabric and epoxy resin composite sample by VARTM method. In order to increase the fiber content, pre-compression method is applied to the ram fabric stack before the epoxy resin is injected into the fiber fabric, and vacuum compression, hot compression with high pressure and temperature are used to compress the fiber bundle, and they have examined the compression reactions of the fabric stack under hot compression conditions. They have stated that hot compression increases the ramie fiber content and the mechanical properties of the composites [5].

Zhang et al. have produced one-way carbon fiber reinforced composite boards in three different processes using the fast curing epoxy resin by VARTM method. They have concluded that the preheating process is suitable for improving the

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processing efficiency in the VARTM method with good mechanical properties [6]. Durgun et al. have produced composite parts with carbon fiber and resin by using vacuum bagging and vacuum infusion method and applied tensile and bending tests to the samples produced by these two production methods. They get the highest results in the vacuum infusion method [7]. Wang et al. have designed a test device to examine the compression behavior and permeability of the preforms during VARTM. In order to examine the resin flow effects and thickness change of preforms, the device has carried out four tests and stated that if the number of layers increases, the permeability of the plane decreases and the preform thickness is influenced by the liquid viscosity and final filling time [8]. Durgun et al. have produced polymer based carbon and glass fiber reinforced composite materials by hand lay-up, vacuum bagging and vacuum infusion methods and compared the mechanical properties of these samples. They obtain the highest values in the vacuum infusion method [7].

Balikoglu et al. have performed a three-point bending test for sandwich composite boards with laminate plans of the hull body provided by Producer Company and produced in the laboratory by the VARTM method [9]. Sevkat et al. have investigated the tensile strength of needle-woven glass-fiber reinforced epoxy composites, fabricated samples using VARTM and hand lay-up methods and tested these samples under tensile load. They report that the samples produced using VARTM method have higher load than the samples produced by hand lay-up [10]. Engine hood is produced by the stagnant vacuum infusion method, the assembled parts are assembled to form the motor assembly and the piece is measured by optical scanning and geometric accuracy analysis is performed [11].

2. MATERYAL AND METHODS

2.1. Workbench production by vacuum infusion

In order to manufacture samples with vacuum assisted resin infusion molding method, a workbench different from the ones previously designed for this method was manufactured with a tempered surface glass and a heat sink dissipating homogenous heat at the bottom (Fig. 1.a,b. The workbench had the sizes of 1.500x1.500x1.00 m and the outer surface and chassis were made of MDF material. The top surface which was the composite production area was made of 10 mm thick tempered (thermos glass) glass resistant to 800°C. This glass surface is heated underneath in a homogeneous manner with a heat sink filled with marble dust and included 5 pieces of 3000 W rod heaters. The vacuum required for infusion was provided by a vacuum pump with a capacity of 130 l/min, vacuum level of maximum 2 Pa and 1/3 HP power. The thermostat sensor was placed at the midpoint of the heat sink at the bottom of the workbench and could control the homogeneously distributed temperature.

2.2 Experimental procedures

In the first stage of our study, we have produced a vacuum infusion machine which has many properties together and will provide our production of layered composites. In order to produce the sample with the vacuum-assisted resin infusion molding method, tempered surface glass, a heat pool radiating from the bottom and a different machine are designed different from the other machines previously designed for this method (Figure 1.a, b). Three different fibers (Kevlar, Carbon and Aramid) are used during production. The production of the composite is performed as shown in Fig. 1 c, d by using the fibers given in Fig. 2.b, c, d,

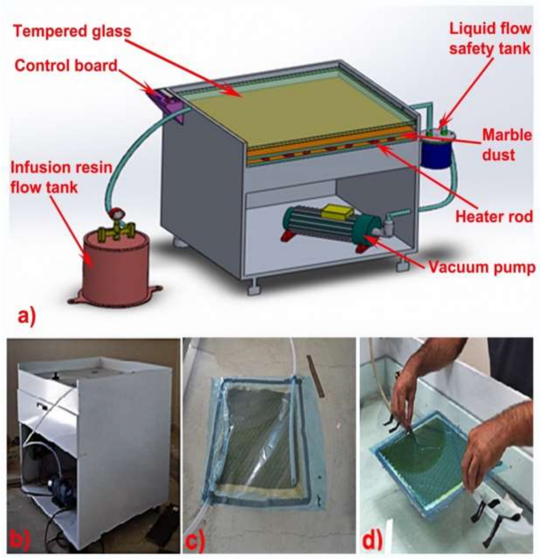

Figure 1. a)Vacuum infusion bench schematic view b) photograph c-d) Production image.

2.3. Materials used in composite production

Three different fibers as Kevlar, Carbon and Aramid were used during production. Table 1 shows these fibers used. In addition, a total of 300+12+24+18 =354 ml mixture including 300 ml Hexion LR 285 epoxy resin, 300 x 0.04 = 12 ml Nutanox M-50 hardener, 300x0.08= 24 ml pigment and 300x0.06= 18 ml Akcobalt CX1-6 cobalt (accelerator) was used. The mixture which was initially heterogeneous was thoroughly homogenized by mixing for 2 minutes.

2.4. Composite production stages

The temperature for the manufacturing was adjusted by performing the cleaning control of manufacturing surface of the workbench, the control of heat sink, vacuum pump, thermostat, thermometer, cocks and valves; when the bench heated and reached to a constant heat value; it was adhered with double-sided adhesive tapes as shown in Fig. 1.c,d around an area at least 50 mm wider than the sizes wanted to be manufactured. In the area within the tape, three layers of mold release agent were applied with the aid of a non-dusting cloth which was not too soft. The fibers were then cut in the sizes of 310 x 310 mm (if a sheet of 300 x 300 mm size was desired to be manufactured, the fiber should be cut leaving 10 mm margin from the edges). The fibers cut according to the desired design were laid in the vacuum area. Peel ply was laid on the fibers placed into the waxed (mold release) region (When the peel ply was being cut, it should be cut by leaving 20 mm margins from 3 edges (resin strip) and 60 mm from the other edge). Peel ply facilitated not only the flow of the resin as well as the separation of the produced material from the mold. After the peel ply was laid, a resin line was installed to make resin flow through the resin tank. A spiral hose and a normal transparent hose were used for resin line, the transparent hose was connected to the spiral hose from one end, and this spiral hose is coiled with holes and ensures the balanced progress of the infusion by forming the vacuum through the spiral.

Fig. 1.c shows its form covered with a vacuum-ready vacuum bag. The vacuum line was installed on the opposite side of the resin line. The vacuum indicator was connected to the vacuum infusion mechanism and the vacuum pump was opened. The ports providing resin pass were connected to the mechanism. The workbench was waited until it reached to the desired heating value and the heat setting was kept constant. The hoses were then connected to the ports and the resin flow was started and the process was continued until all the points of the mold were wet with the resin (Fig. 1.d). The last corner of the mold got wet. After all the points were wetted, all resin feed lines were closed with valves or clamps. During this infusion process, heating was continued until the infusion was completed at 50 ° C and the drying was completed (in our experiments, 2 hours) with the underfloor heating system. The part was then waited for about 2 hours at 50 °C until fully hardened under vacuum. After waiting for two hours, the sealing tape was removed, the bag was first removed from the mold and the resin flow lines were cleaned. Then, the part was removed from the mold. It was visually checked if or not there were any air bubbles on the surface of the produced sample and the resin was homogeneously distributed, tensile sample for the tensile test was prepared by marking according to the fiber type used.

3. RESULTS AND DISCUSSION

Tensile stress and strain values of Kevlar, Aramid and Carbon Composite samples are given in Table 1. Tensile tests were carried out in accordance with the EN 100022 standard on the tensile testing device in the Engineering Faculty Laboratory in Munzur University. In both experiments applied to all samples, values are nearly similar. It is seen that the aramid tensile sample value is close to the Kevlar's. Breaking values of the samples depending on stress area are within the range of 65-85 MPa. According to the test results of the composite carbon tensile sample, breaking value is 270MPa in 2.00mm It is obvious that tensile strength of the carbon composite sample is higher than the Kevlar and Aramid samples.

Table 1. Tensile test results

Sample Code	Tensile Strength (MPa)	Elongation (%)
F:1-1 (Kevlar)	60,2464	2,31
F:1-2 (Kevlar)	86,3882	2,57
F:2-1 (Aramid)	67,9012	1,69
F:2-2 (Aramid)	78,5880	1,73
F:3-1 (Carbon)	256,895	2,45
F:3-2 (Carbon)	276,829	2,10

The reinforcing materials used in the sample are shown in Figure 2.

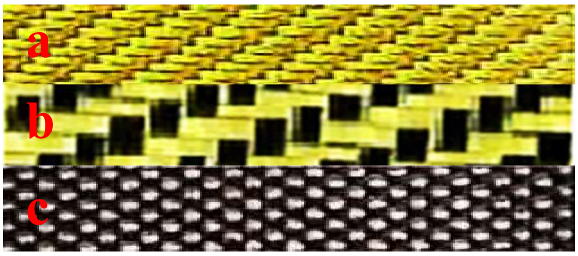

Figure 2. Fibers used in production a)Kevlar b)Aramid c)Carbon

In the SEM analyzes of composite Kevlar tensile sample in Fig 3 the images of resin and fiber structure are examined in detail in different magnifications. It is observed that micro and macro gaps do not appear and full penetration is achieved in the absorption of the resin to the fiber structure by the infusion method. This is also advantageous in the production of complex shaped structures. Figure 3.a shows the composite Kevlar sample at 40x magnification. Kevlar fabric fibers, epoxy resin and emitter film is shown in the image. In the section mentioned, the boundary between the emitter film and the resin, and the low wall thickness of the sample (1.30 mm) show the estimated dissociation point during cutting for SEM analysis. Figure 3.b shows composite Kevlar sample at 80x magnification. The image (1) shows the horizontal Kevlar fibers, (2) and the vertical Kevlar fibers. In the regions indicated by (3), there are gaps resulting from the separation of the emitter film during the cutting of the sample. Figure 3.c shows composite Kevlar sample at 300x magnification. In the image, horizontal and vertical structure of the Kevlar fabric appears more clearly. Horizontal fibers indicated by (2) are highly void-free and detail (3) is frayed at 300x magnification when the horizontal fibers are cut for SEM images. Fraying is caused by the gap appearing during the separation of the emitter film in the cutting process, which can be eliminated by cutting with higher speed and harder cutting tools, but does not preclude detailed examination of the material. Figure 3.d shows composite Kevlar sample at 1000x magnification.

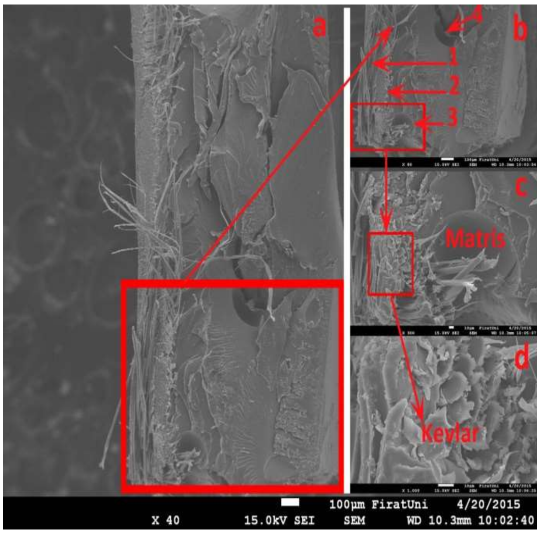

Figure 3. SEM analysis of composite kevlar tensile sample a)27x b)80x c)300x d)1000x

Figure 4.a shows composite Aramid sample at 30x magnification. Figure 4.b shows it at 100x magnification. Image shows the cracking region of Aramid fiber and epoxy resin that appears during cooling. In the sample production method, the appropriate heat value can be determined by examining the crack formation and by trying to increase and decrease the temperature of the machine. Figure 4.c shows the composite Aramid sample at 700x magnification. The image shows the penetration of Aramid fibers with resin. As the structure of Carbon and Kevlar fibers is examined, it is seen that the carbon is more frigid at the cutting points of the cylindrical Kevlar. Figure 4.d shows the composite Aramid sample at 3000x magnification. Carbon and Kevlar surface images show the superiority of hardness and strength properties of carbon.

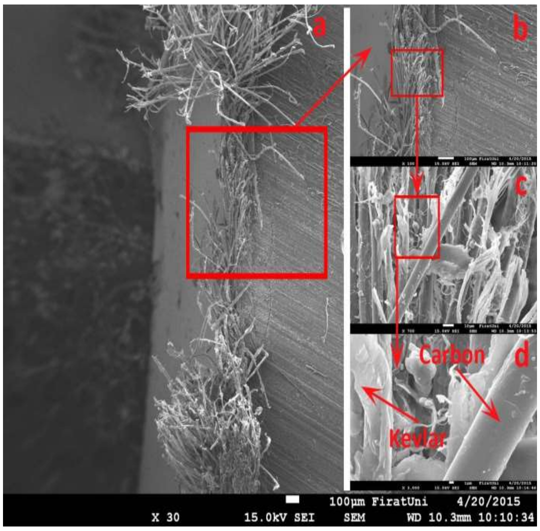

Figure 4. SEM analysis of composite Aramid tensile sample a)30x b)100x c)700x d)3000x

Figure 5.a shows composite Carbon sample at 200x magnification. The image shows the carbon fabric fibers and the epoxy resin. Figure 5.b shows composite Carbon sample at 500x magnification. The image shows horizontal and vertical structure of the carbon fabric fibers. Remarkably, carbon fibers tips are not frayed but they are fragile due to their small particle size. Figure 5.c shows composite Carbon sample at 2.500x magnification. The image shows the horizontal fibers and epoxy resin of the carbon fabric. Carbon fibers have circular cross-section and no gap. They consist of a dense bundle of fibers and as the fibers are continuous; this structure gives high strength values in terms of tensile strength. Figure 5.d shows composite carbon sample at 10,000x magnification. This image allows very detailed examination of the carbon fabric horizontal fibers. The details of the cross-section and the inner structure of the fiber do not include any cracks or gaps.

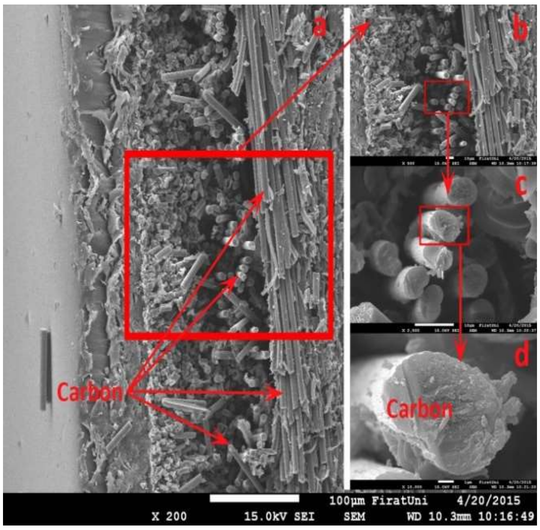

Figure 5. SEM analysis of composite carbon tensile sample a)200x b)900x c)2.500x d)10.000x

4. CONCLUSIONS

In this study, the effects of vacuum assisted resin transfer molding method on composite materials are investigated. The results of the production and improvement of the test set are listed below.

- Vacuum assisted resin infusion molding test set is successfully manufactured.
- Heating of the glass on the intermediate test set on the epoxy tin, used as a resin, by the lower resistances of the glass in order to proceed without forming fluid and air space on the Temper glass results very advantageously during the production phase of the material.
- The differences of the produced materials are compared with the tensile tests. The tensile samples with carbon fiber are more advantageous mechanically and the results are much higher in the samples having the

minimum wall thickness (0.5 mm) in evaluations according to the wall thickness.

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