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ISSN: 2299-128X
Polish Society of Composite Materials

Development of a method for producing composite parts of the TRIGGO electric car based on A.S.SET epoxy resin powder – feasibility study

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https://doi.org/10.62753/ctp.2024.06.4.4

Abstract

Composite materials due to their outstanding mechanical properties and light weight are becoming increasingly important in the automotive industry, helping to develop lighter, more durable and environmentally friendly vehicles. It is especially important in the context of electric cars such as TRIGGO. It is an innovative electric vehicle (EV) designed with a focus on urban mobility. One of the unique features of this car is its compact design, aimed at providing a flexible solution for city driving. In this paper a method for manufacturing composite components of the TRIGGO electric car body by pressing technology, based on the innovative A.S.SET resin is described. It was confirmed experimentally that selected components of the TRIGGO vehicle body are feasible to be fabricated by pressing technologies using SemiNEMpreg pre-impregnated material based on A.S.SET epoxy resin. The studied technologies cover thermoset sheet forming using a membrane press or a hydraulic press, also using a vacuum-assisted oven. These technologies were adapted to the requirements of manufacturing composite parts, with a special focus on the cost-effectiveness of the process. Owing to the use of the fast-crosslinking snap-cure epoxy resin with the trade name NEMresin (known as A.S.SET), it was possible to shorten the crosslinking process to 15 minutes. The studies made it possible to select the type of mold depending on the geometry of the component and the applied technology. The studies led to the determination and matching of the type of component to the type of mold and predestined manufacturing technology, taking into account the most important factors affecting the start of mass production, such as the number of pieces, the surface quality of the component, i.e. roughness coefficient and surface finishing, mold cost, process time, process cost, required repeatability, quality of the target component structure, as well as the cost of finishing. The developed technologies are innovative and allow the low-cost batch manufacture of composite parts for the automotive industry.

Keywords: GFRP, TRIGGO electric car, epoxy powder resin, thermoset sheet forming, automotive

Introduction

Composite materials are becoming increasingly important in the automotive industry, helping to develop lighter, more durable and environmentally friendly vehicles. The main reason for using composites is to reduce the weight of vehicles. Composites, such as carbon or glass fiber reinforced polymers, are replacing heavier materials such as steel, improving energy efficiency and vehicle performance. The importance of this technology is growing, especially in the context of electric and autonomous cars. In

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addition, composites are more corrosion-resistant and effectively dissipate energy during collisions, increasing passenger safety and vehicle life [1-4].

Introducing new electric cars for use in crowded cities requires the use of lightweight composite materials for their design. It is forecast that the use of polymer composites in the automotive industry could increase up to four times by 2025 compared to 2018. This will likely be done by replacing individual structural components made of classical materials with composite structures. At a later stage, the entire vehicle will be manufactured from composites [5, 6]. This kind of use of polymer composites is currently being employed in the construction of many electric cars, such as BMW vehicles.

With the development and expansion of fiber reinforced polymers (FRP) to produce structural components, the price of composite materials is gradually decreasing, making them increasingly attractive to automotive manufacturers. Technologies that enable the production of vehicle structural components in rapid process operations include: high-pressure resin transfer molding (HP-RTM), prepreg compression molding, and liquid compression molding (LCM) [7-11].

The type and quality of the product determines the choice of technology, which in turn has a direct impact on production costs. The broader design phase of composite parts should also consider, besides product-related factors, the efficiency of the method, energy and utility requirements, additional operations, the amount of production scrap, the cost of machinery, equipment and tooling, including consideration of human and environmental nuisances. The typical production volume of truck parts ranges from 5,000 to 20,000 units per year. For passenger cars, the production scale is larger, ranging from 80 thousand to 500 thousand parts per year [7]. The total cost of tooling for producing composite parts is lower than the cost of tooling for making a metal sheet stamped product because a stamped product generally requires several operations and different tooling. In the automotive industry, the cost of tooling is essential, and the determining value is the size of the production run [12]. Figure 1 shows the suitability of various methods of manufacturing products with fiber reinforcement for the mass production of parts in the automotive industry.

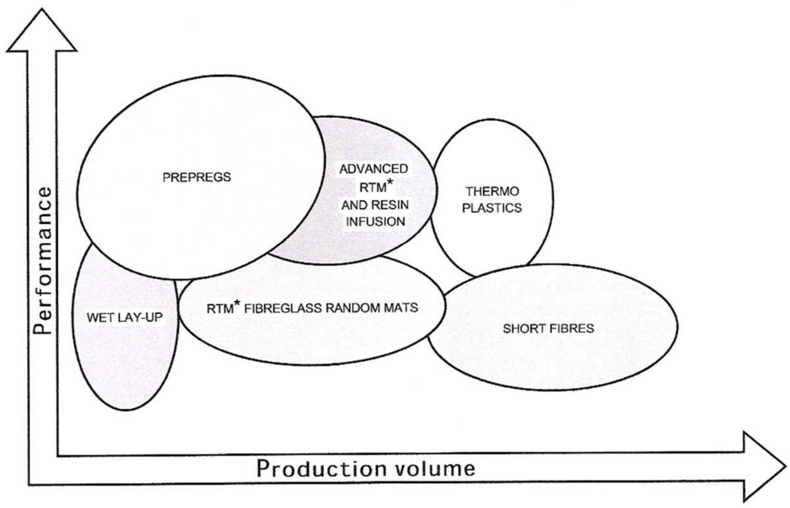

Figure 1. Usefulness of some technologies for manufacturing products with fiber reinforcement to mass produce vehicle parts [13].

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New methods, which are alternatives to classical technology, represent technologies based on the use of powdered epoxy resins [7, 14, 15]. They are dedicated to the batch production of composite parts, owing to their short crosslinking times, and position themselves between the technologies using prepregs and thermoplastic processing shown in Figure 1. However, manufacturing composite parts utilizing hydraulic and membrane presses also requires more robust molds, which are more expensive and demanding than molds dedicated to unit production.

TRIGGO is an innovative electric vehicle (EV) designed with a focus on urban mobility. One of the unique features of this car is its compact design, aimed at providing a flexible solution for city driving. It combines the advantages of both a car and a motorcycle, offering the ability to reduce its width for better maneuverability in traffic. The TRIGGO vehicle utilizes composite materials in its construction to keep weight low and increase efficiency, especially in urban environments where every kilogram saved translates to better energy consumption.

The purpose of the research presented in this article is to develop a process for manufacturing the TRIGGO vehicle's chassis structure components using A.S.SET single-component powder epoxy resin. Figure 2 shows a representative group of chassis components that were subjected to feasibility analysis.

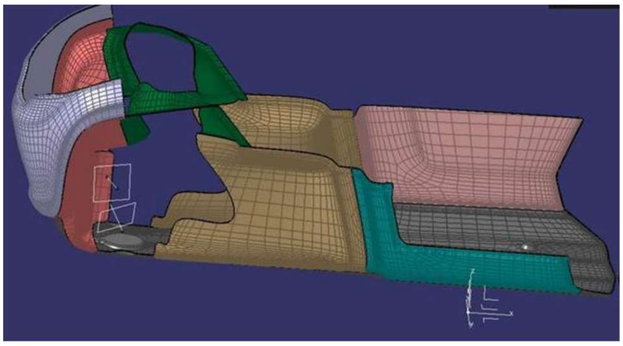

Figure 2. CAD model of TRIGGO vehicle body components to be made from A.S.SET epoxy powder resin.

Materials and methodology

The powdered epoxy resin, A.S.SET, made by New Era Materials, was used to manufacture the body elements of the electric car named TRIGGO, which in the temperature range of 80 ÷ 120°C shows reduced viscosity and perfectly impregnates the reinforcing fibers. Above 110°C, it undergoes a crosslinking process. The crosslinking time is about 8 min and depends on the thickness of the manufactured product. After curing, the product has thermoset properties and is heat resistant up to 350°C. The processing properties of A.S.SET resin enable the preparation and launch of the batch production of components made of FRP in a short time. In this work, A.S.SET resin was used as SemiNEMpreg 4010 prepregs based on NEMresin 4010 (formerly A.S.SET 4010) resin with glass fiber reinforcement, developed at New Era Materials.

SemiNEMpreg 4010 is made of glass fabric pre-impregnated with A.S.SET resin. It is designed for parts requiring a low air content and good mold surface reproduction. SemiNEMpreg 4010 is recommended for vacuum bag molding and hot molding in a vacuum-assisted press. The properties of the SemiNEMpreg 4010 material are shown in Table 1.

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Manufacturing the vehicle composite components consisted of heating a set of sheets to a certain temperature and then pressing them into a mold. The process parameters were as follows: i) pressure from 10 to 150 MPa; ii) crosslinking temperature in the range of 120 ÷ 140°C (recommended range); iii) pressing time in the range of 8 ÷ 10 min. Figure 3 schematically shows this technology. It significantly shortens the production process in both the material preparation and manufacturing phases. Nevertheless, it requires suitable molds that meet the process requirements, the complexity of which depends on the product geometry.

Table 1. Selected properties of SemiNEMpreg 4010 material made by New Era Materials.

Product				SemiNEMpreg 4010
Property		Method	Unit	
Material data	Resin type	-	-	Epoxy
	Resin content	-	wt%	45±2
	Reinforcement type	-	-	GF350
	Reinforcement areal weight	ISO 3374:2000	g/m^2	350±5
	Fabric weave	-	-	Twill 2/2
Storage	Time	-	mos.	12
	Temperature	-	°C	-18
Outlife	Time	-	days	5
	Temperature	-	°C	20
Mechanical	Tensile strength 0°	ISO 527-4:2012	MPa	340
	Strength Modulus 0°		GPa	15
	Flexural Strength 0°	ISO 14125:2001	MPa	519
	Flexural Modulus 0°		GPa	15
	Tensile strength 90°	ISO 527-4:2012	MPa	416
	Strength Modulus 90°		GPa	17
	Flexural Strength 90°	ISO 14125:2001	MPa	664
	Flexural Modulus 90°		GPa	17
Thermal	Glass Transition Temp. (DMA)	ISO 6721-1:2011	°C	128±2
	Glass Transition Temp. (DSC)	ISO 11357-5:2014	°C	120±2

a) Stage 1 b) Stage 2

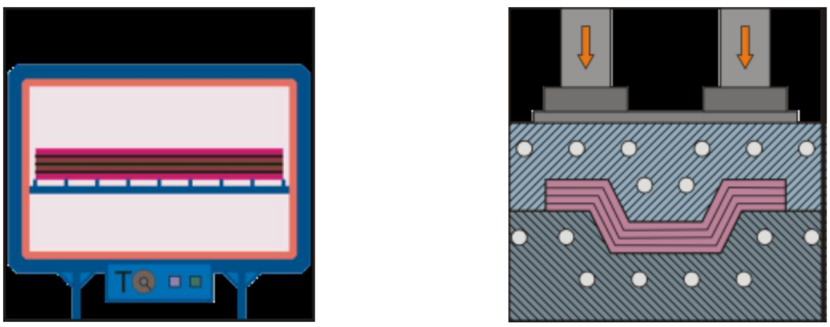

Figure 3. Diagram of composite component fabrication by pressing a) heating plate pack, b) pressing plate pack.

When using SemiNEMpreg, the air vent process should continue at least until the maximum vacuum is reached for two-stage vacuum pumps. For the safety and quality of the composite, it is recommended to extend the venting time by 5 min after reaching the maximum vacuum, which usually closes the process in about 10 min.

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Results

The technology based on A.S.SET is comparable to the steel sheet stamping technologies popular in the automotive industry. Like sheet stamping, the design and complexity of the molds depend on the composite part being produced. The main difference is that steel sheets have a much higher plastic deformation capacity (about 40%) than glass fiber-reinforced materials (1-2%).
The manufacture of composite parts by pressing methods has limitations, which include:
- the height of the embossing, since the fiber composite material does not deform like a metal sheet
- the inclination of the angles of the vertical walls that allow the part to be pulled out of the mold
- the inability to create internal tabs as a consequence of restrictions on the movement of the fibrous material in the molds.

Because of lower pressures, manufacturing parts on a membrane press enables the use of low-cost molds (PA12 printed, composite, or wooden), unlike a hydraulic press, which requires expensive metal molds. Making metal molds is economically viable only if high-volume production is carried out.

When analyzing the feasibility of different technologies for manufacturing TRIGGO vehicle components, the main considerations were:
- technological limitations (embossing height, inclination of the angles of the side walls, ratio of flat surface to vertical areas)
- the need to use displacers, actuators and other elements supporting manufacturing in hydraulic molds
- the type of production (unit, small batch, large volume)
- the pressure used, necessary for proper manufacture of the component (10 MPa for a diaphragm press or 150 MPa for a hydraulic press)
- the cost of the mold.
Figure 4. shows a selection of TRIGGO vehicle body components that were made from NEMpreg in various molds.

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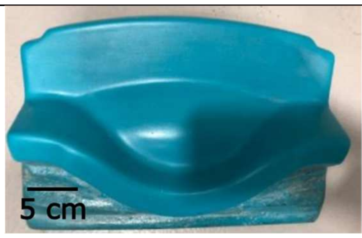
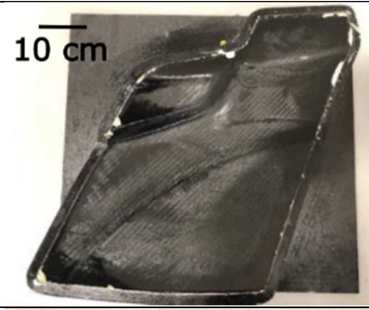
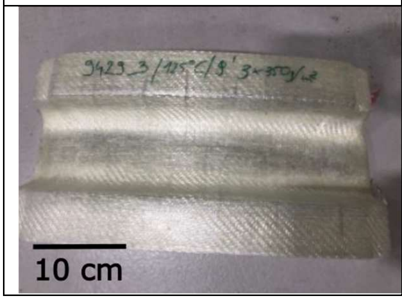
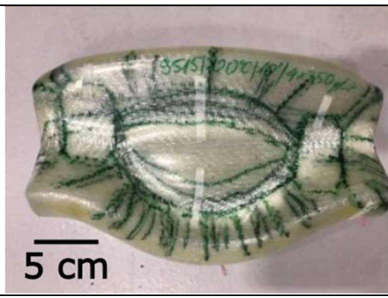
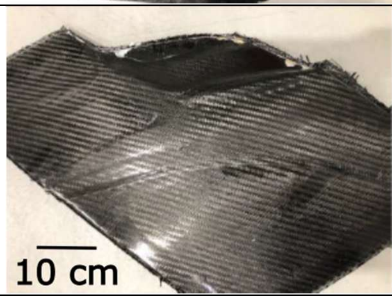
Wooden mold, membrane press	Composite mold, membrane press	Hybrid mold, membrane press
		
		

Figure 4. Composite parts made on membrane press using wooden, composite and hybrid molds.

Preliminary tests conducted on the manufacture of TRIGGO vehicle parts made it possible to define the requirements. One of the most important was the quality of the reproduced surface. In addition, ease of de-molding, temperature stability of the mold and part, as well as methods of joining the parts were important. The main NEMpreg problems observed during the manufacture of the composite parts of the TRIGGO vehicle were the overly rigid structure of the prepregs, which translated into their difficult moldability at room temperature, resin spalling during molding, in addition to the inability to properly align the material in the mold with the expected mapping of small radii and curves. Moreover, high air content and unsatisfactory infiltration rates were found.

Based on the above observations, the main requirements considered in the development of SemiNEMpreg 4010 were:
- easy moldability of the material at room temperature
- formability to use low pressure on a membrane press
- cost-effectiveness of the molds and tooling
- the ability to produce parts using a vacuum-assisted hydraulic press
- the possibility of venting during the process while the resin is still in a liquid state
- perfect mold filling, guaranteeing excellent surface reproduction.

To achieve the best quality of the composite, a minimum 2-stage pressure ramp was used. The first stage involves liquefying the resin to a state that provides the minimum viscosity for the process at minimum pressure, which should not exceed 10 MPa.

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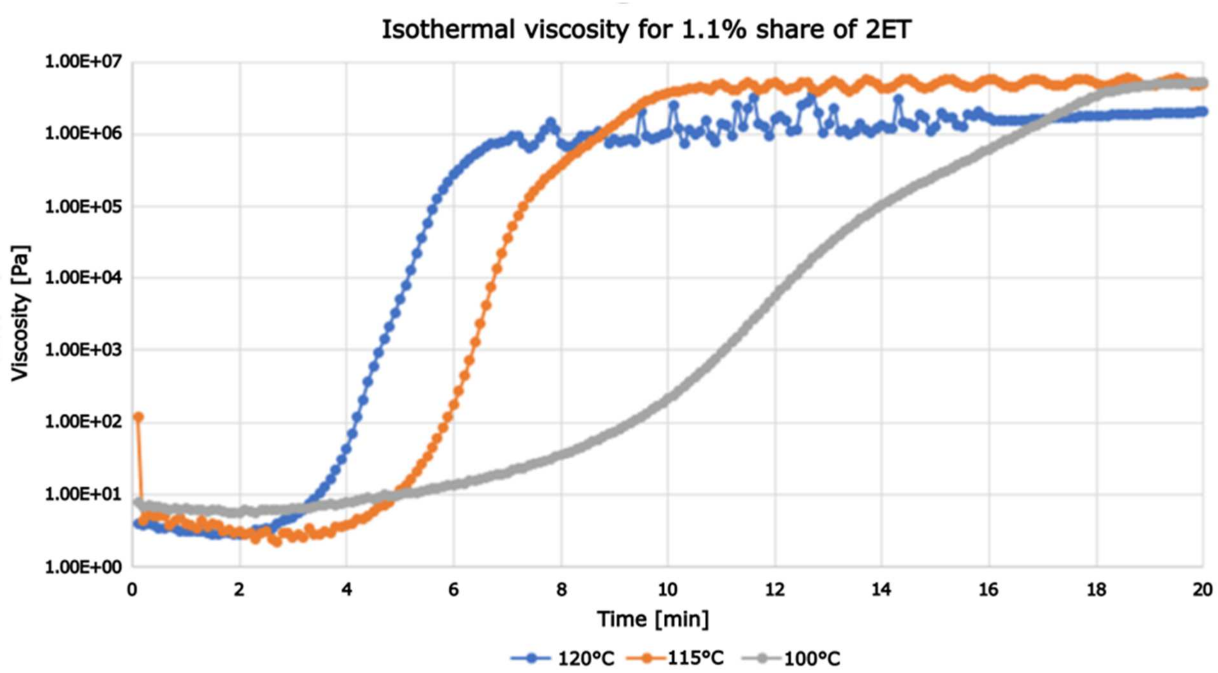

Figure 5. Viscosity curves as a function of time and temperature.

The time of the first step depends on the temperature of the beginning of crosslinking, and for example, for 100°C the recommended time is 2 to 3 minutes.

The next step requires crosslinking at higher pressures, i.e. 80 MPa. The duration of the second step was derived from the curves shown in Figure 5 and for 100°C it was a minimum of 23 minutes.

Placing the material in the mold required heating the mold to about 40°C to achieve the best quality of the composite. Heating the prepreg material to the same temperature is also recommended to facilitate its placement in the mold. It is necessary to provide vent paths for each layer of the material, which can be accomplished by using dry fabrics of the same type as in the structure, but of low aerial weight. The laid structure is covered with an unperforated release film and vent fabric. In Table 2 the processing parameters are given and in Figure 6 the process is shown.

Table 2. SemiNEMpreg 4010 processing parameters.

	Slow curing	Standard curing
Debulking time [min]	5-10	
Heating ramp [°C/min]	2-3	
Dwell temperature [°C]	73-77	
Dwell time [min]	7	
Curing temperature [°C]	100	110
Curing time [min]	35	20

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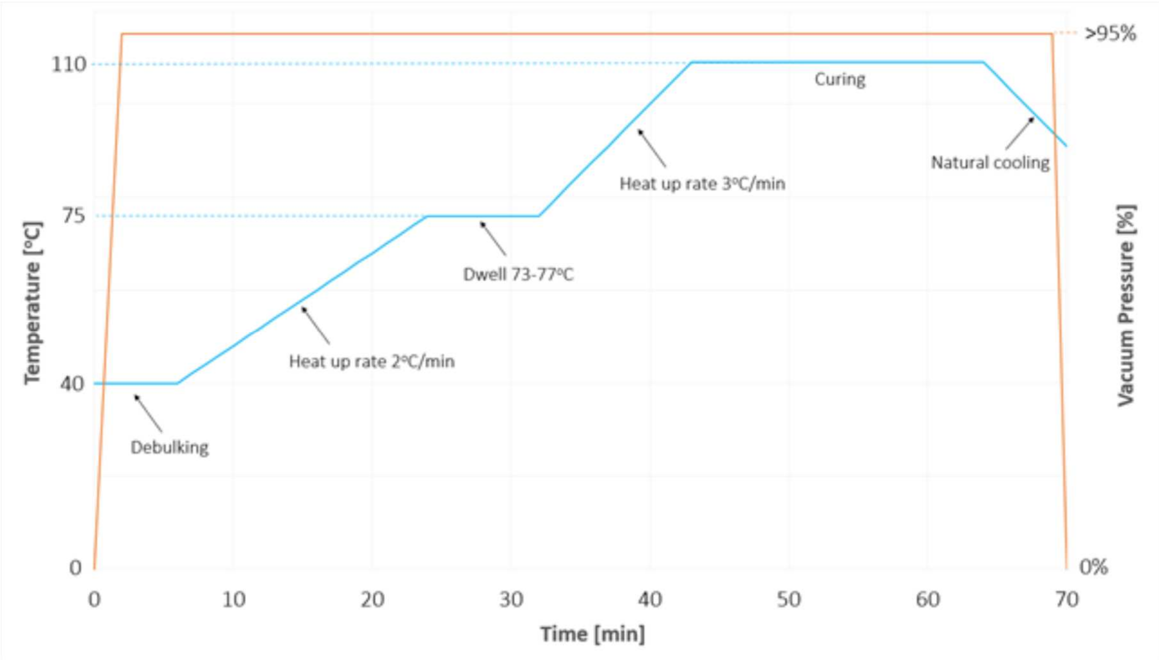

Figure 6. Curing profile of SemiNEMpreg 4010 in manufacturing process of TRIGGO vehicle components.

The TRIGGO vehicle composite parts were manufactured using different molds and technologies as described below.

1. Fabrication of vehicle components using a single-sided mold heated in an oven with vacuum bag assistance.

In a mold without heating channels, the SemiNEMpreg 4010 material was placed, a vacuum bag was installed, and then, after checking the vacuum, the whole system was put into the oven, the temperature control of which was adjusted to a ramp that allowed the right heating process to be achieved and the material to be held at the right temperature (according to the process shown in Figure 6).

Two types of molds were tested in such a process: a composite mold made by cavity technologies and one made by additive manufacturing from PA12 material. Figure 7 shows the TRIGGO body parts made with this technology.

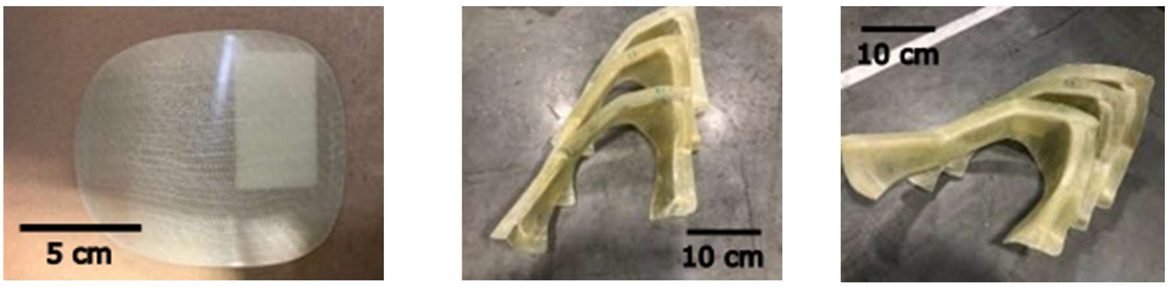

Figure 7. TRIGGO body parts made in single-sided mold heated in vacuum-assisted oven using bag, from left: hatch, cowl_D_Left, cowl_D_Right.

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2. Fabrication of vehicle components in a single-sided mold heated by oil with vacuum bag assistance.

The SemiNEMpreg 4010 material was placed in a mold with heating channels, a vacuum bag was installed, and oil heating started after checking the vacuum. The heating run was adjusted to a ramp to achieve the right heating process and hold the material at the right temperature (according to the process shown in Figure 6). A single-sided aluminum heated mold made with cavity technologies was tested in such a process. Figure 8 shows the vehicle parts made by means of this technology.

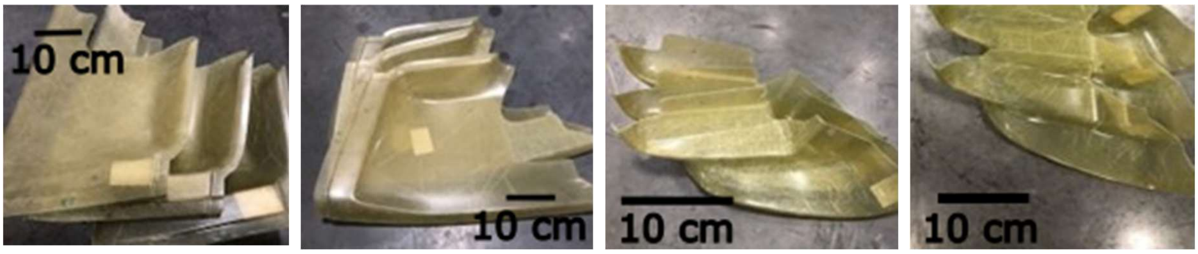

Figure 8. TRIGGO body parts made in one-sided heated mold (oil heating) with vacuum bag assistance, from left: cowl_B_Left, cowl_B_Right, cowl_A_Left, cowl_A_Right.

3. Fabrication of vehicle components in a single-sided heated mold in a membrane press with vacuum bag assistance.

The SemiNEMpreg 4010 material was placed in a mold without heating channels, then placed on a membrane press to achieve vacuum, and next heated with infrared heaters. The heating run was adjusted to a ramp according to Figure 6. In the process, a composite mold made of carbon fiber was tested by means of the mapping method. Figure 9 shows the components of the TRIGGO vehicle made using this technology.

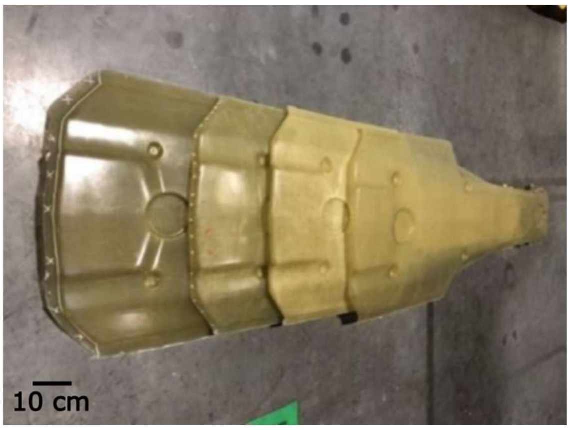

Figure 9. TRIGGO vehicle parts made in single-sided heated mold in membrane press with membrane vacuum assistance (casing bottom).

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4. Fabrication of vehicle components in a single-sided heated mold in a membrane press with vacuum bag assistance.

In a mold without heating channels, material in the form of SemiNEMpreg 4010 was placed in the mold, a vacuum bag was installed, and then, after checking the vacuum, the whole system was placed in a membrane press. The heating control was adjusted to a ramp that allowed the material to be heated and held at the right temperature according to the process shown in Figure 6. Also in this case, a carbon fiber composite mold made by the mapping method was tested. Figure 10 shows the finished car parts made utilizing this technology.

Figure 10. TRIGGO car body parts made in single-sided heated mold in membrane press with vacuum bag assistance, from left: casing, casing_C_right.

5. Fabrication of vehicle components in a double-sided heated mold in a hydraulic press with vacuum assistance, achieved by a lip seal, in the form of vacuum inside the mold.

Material in the form of SemiNEMpreg 4010 was placed in a double-sided metal mold with heating channels. Then, oil heating was started, the course of which was adapted to the process ramp shown in Figure 6. The press was then closed, and vacuum was started, which remained the same throughout the process. Figure 11 shows the TRIGGO body parts made with this technology.

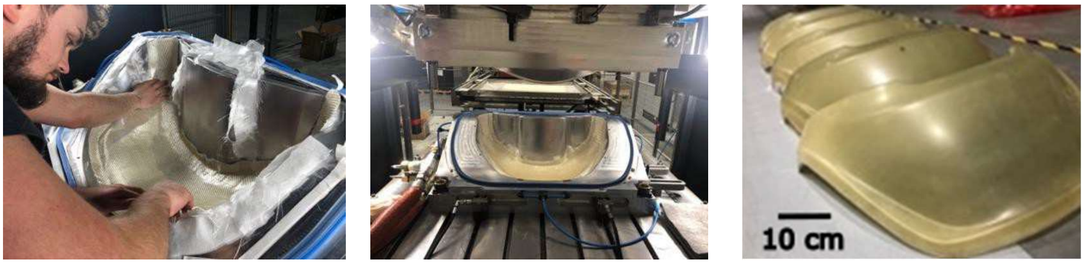

Figure 11. Process of making front bumper in double-sided heated mold in vacuum-assisted hydraulic press, from left: laying prepreg, placing mold on press, final parts.

All the fabricated car parts, after finishing, were combined into a layout corresponding to the 3D model (Figure 1), as shown in Figure 12. If it is necessary to join (bond) all the fabricated parts, they have an area outside the component to enable the bonding or nailing process. All the parts are of very good quality and accuracy of manufacturing. Comparison with the assumed CAD model confirms the correctness of their manufacture.

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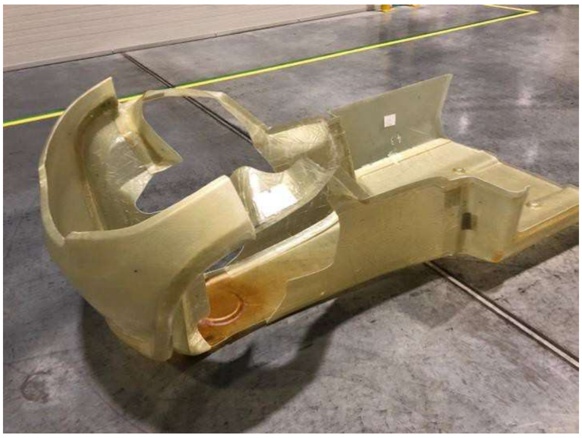

Figure 12. TRIGGO body parts fabricated as part of the project, connected in layout that matches assumptions.

Conclusions

The aim of the research was to develop a method for manufacturing composite components of the TRIGGO electric car body by pressing technology, based on the innovative A.S.SET resin. The employed technologies allow us to eliminate many disadvantages and limitations of previous methods of manufacturing composite materials. It was confirmed experimentally that selected parts of the TRIGGO vehicle body are feasible to be fabricated by pressing technologies using SemiNEMpreg pre-impregnated material based on A.S.SET epoxy resin. The technologies were adapted to the requirements of manufacturing composite parts, with special focus on the cost-effectiveness of the process. Owing to the use of a fast-crosslinking snap-cure epoxy resin with the trade name NEMresin (known as A.S.SET), it was possible to shorten the crosslinking process to 15 minutes, compared to classic methods of manufacturing composite materials, in which the crosslinking process itself takes several hours. It was possible to speed up the process of laying the material in the mold (preforming) thanks to the development of the flexible SemiNEMpreg material and optimization of the preforming process allowing the laying of 5 layers of reinforcement with an area of $1m^2$ in 15 min. When classic materials (prepregs from other manufacturers or NEMpregs from New Era Materials) are used, there is the problem of the presence of very high viscosity (prepregs) or stiffness (classic NEMpregs), hindering the preforming process. In addition, a method of pre-stacking the structure of SemiNEMpregs outside the press was developed and tested, further accelerating and facilitating the preforming process.

The studies made it possible to select the type of mold depending on the geometry of the component and the applied technology. The following types of molds were tested:

- printed molds produced by additive manufacturing (selective laser sintering - SLS)
- composite molds (reinforced with carbon or glass fibers)
- heated metal molds, single-sided
- heated metal molds, double-sided.

The conducted research made it possible to match the type of mold to the manufacturing technology, considering the cost-effectiveness as well as the advantages and disadvantages of each solution.

The manufacture of the composite parts in the following technologies was optimized:

- thermoset sheet forming using a membrane press
- thermoset sheet forming using a hydraulic press

- thermoset sheet forming using a vacuum-assisted oven and a membrane press.

This led to the determination and matching of the type of component to the type of mold and predestined manufacturing technology, taking into account the most important factors affecting the start of mass production, such as the number of pieces, surface quality of the component (roughness coefficient and surface finishing), mold cost, process time, process cost, required repeatability, quality of the target component structure, in addition to the cost of finishing. The developed technologies are innovative and enable the low-cost batch manufacture of composite parts for the automotive industry.

Acknowledgements

The work was carried out under project POIR.01.02.00-00-0285/16 entitled, “Special body with increased durability for the variant of the “L” category vehicle with increased mobility “Triggo”, intended for operation in automatic rental networks “carsharing”, and the technology of serial production of its elements based on innovative epoxy resins A.S.SET.”, was funded by National Centre of Research and Development.

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