Mechanics

Vacuum furnace with pressing capacity

Tamaz Khmelidze*, Revaz Sakhvadze**

* *Professor, Georgian Technical University, Department of Construction Machinery, Tbilisi, Georgia,*
** *PhD, Georgian Technical University, Department of Civil and Industrial Construction, Tbilisi, Georgia*

Following article considers design for vacuum furnace with pressing capacity to create a plastic and polymer composite material and achieve proper physical and mechanical properties for them. Major advantage of machine is to make possible use proper compounds in vacuum chamber and to apply pressing force and temperature at the same time. A composite material is a material which is produced from two or more constituent materials. These constituent materials have notably dissimilar chemical or physical properties and are merged to create a material with properties unlike the individual elements. Within the finished structure, the individual elements remain separate and distinct, distinguishing composites from mixtures and solid solutions. Composite materials are generally used for buildings, bridges, and structures such as boat hulls, swimming pool panels, racing car bodies, shower stalls, bathtubs, storage tanks, imitation granite, and cultured marble sinks and countertops. Typical engineered composite materials include: reinforced concrete and masonry, composite wood – plywood, reinforced plastics - fiber-reinforced polymer or fiberglass, ceramic matrix composites, metal matrix composites and other advanced composite materials.

composite materials, vacuum furnace, heat press, fiber-reinforced polymer, prc, frp

Fiber-reinforced polymer composites (FRP) and particle reinforced composites (PRC) have a growing potential for multi-functional applications. The original plastic material without fiber reinforcement is known as the matrix or binding agent. The matrix is a tough but relatively weak plastic that is reinforced by stronger stiffer reinforcing filaments or fibers. The extent that strength and elasticity are enhanced in a fiber-reinforced plastic depends on the mechanical properties of both the fiber and matrix, their volume relative to one another, and the fiber length and orientation within the matrix [1]. New materials can be designed with the variation of polymers and the reinforcing components to meet the requirements of working in hard conditions. A suitable resin for combining the "fiberglass" with a plastic to produce a composite material, was developed in 1936 by du Pont. The first ancestor of modern polyester resins is Cyanamid's resin of 1942. Peroxide curing systems were used by then [2]. Ray Greene of Owens Corning is credited with producing the first composite boat in 1937, but did not proceed further at the time due to the brittle nature of the plastic used. In 1939 Russia was reported to have constructed a passenger boat of plastic materials, and the United States a fuselage and wings of an aircraft. The first car to have a fiber-glass body was the 1946 Stout Scarab. Only one of these models was built. The Ford prototype of 1941 could have been the first plastic car, but there is some uncertainty around the materials used as it was destroyed shortly afterwards. The first fiber-reinforced plastic plane was either the Fairchild F-46, first flown on 12 May 1937, or the Californian built Bennett Plastic Plane. A fiberglass fuselage was used on a modified Vultee BT-13A designated the XBT-16 based at Wright Field in late 1942 [3]. An important factor in establishing a widespread use of new materials as a competitive product is the simplicity and cost of their production technology.

Problem area

It's widely spread to make composites using devices with the possibility of thermal activation of the reaction mass and the effect of static forces on it, over a certain time range. The advantage of devices is that they obtain a good index of density and strength under the influence of the compression. Even though that this sort of device has plenty of advantages it still has some disadvantages. One of those disadvantages is that during the heating process air bubbles are formed. If the process is carried out under atmospheric pressure, the impact of time, temperature and compression do not allow the liquid phases to release the air particles. Therefore, the products obtained have high porosity and reduced mechanical properties. To avoid air bubbles, its highly recommended to perform mentioned thermomechanical processes in a vacuum. There are numerous methods for removing gases from liquids. One of those methods is placing a solution under reduced atmospheric pressure. It makes the dissolved gas less soluble. This technique is often referred to as vacuum degasification. Specialized vacuum chambers are used to degas materials through pressure reduction. low-density particles are discharged to the surface of the liquid, in a vacuum environment and are ejected from the mass because of the pressure gradient. High-temperature vacuum presses are used for this purpose. Modern vacuum temperature presses, which are widely used to create ceramic and metal-ceramic composite materials, are expensive because they operate in high vacuum (10-1 - 10-5 Pa) and temperature modes (up to 1200°C). Due to the technical conditions, the size of the vacuum chamber, as well as geometric dimensions and shapes of the intended product are very small and limited. Therefore, the use of this equipment for creating polymer composites is not beneficial in terms of both technical (size and shape) and economical (high price) aspects. Based on the above analysis, it is expedient to create an acceptable and universal high-temperature vacuum press for polymer composites.

General Requirements

The basic requirements for the new equipment could be following: vacuum: 10-3–10-6 Pa; working temperature range: 20-400°C; load-40 ton; the geometric shape of the composite material 500X500 mm plate, with 4 to 30 mm thickness.

The following steps and variables are considered for the processing of product, using raw polymer materials:

1 - In the liquid state of the substance: viscosity (η), temperature (c) and vacuum degree (P) relation, $\eta = f(c)$, $\eta = f(P)$;

2 - In the transition from molten to solid state: density (ρ) and shear force (F) dependence graph, $\rho = f(F)$. Independent variables and their units: c - Temperature °C; P - Vacuum degree Pa; F - Shear force kgF. Dependent variables: η - Dynamic viscosity Pa s; ρ - Density, g/cm^3.

Solution

With the help of the specified values for independent variables could be achieved: required viscosity in the raw material processing on the one hand and the density of the composite on the other (Fig. 1).

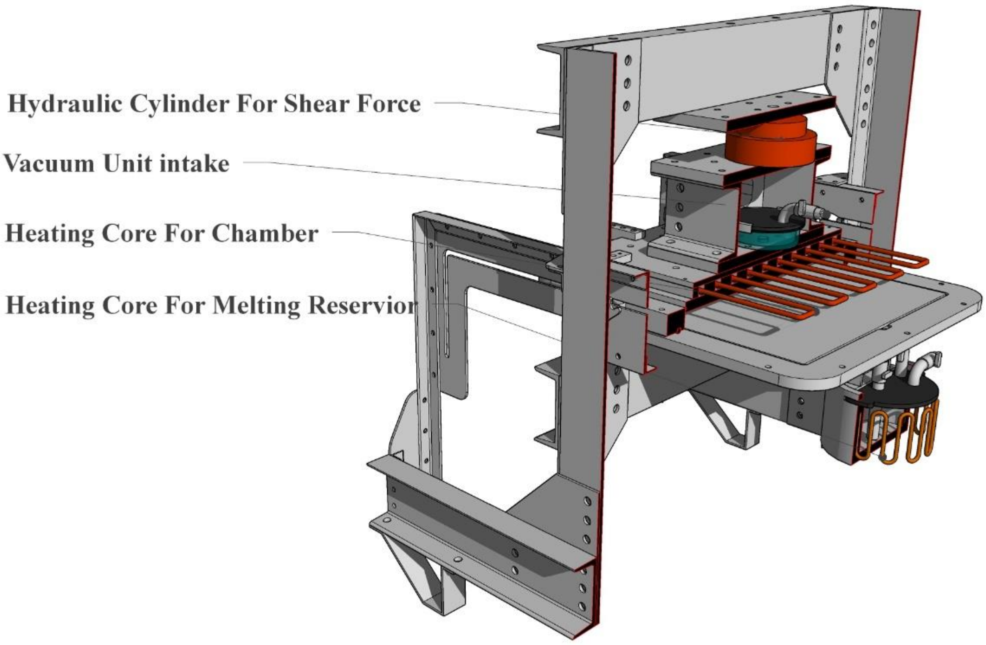

Figure 1. Drawing in perspective, machine equipped with thermal core, hydraulic cylinder and vacuum unit

The viscosity and vacuum quality in the liquid phase are actually due to the need to expel air particles and to inject degassed substance into the fibrous tissues. In addition, at a certain stage of processing with machine, the purpose can only be reached if the viscosity is determined. For example: the flow of liquid substance in the tubes, under the influence of a vacuum. The following equation (1) can be used to determine the flow rate in tubes:

$$\mathrm{Q} = \frac{\Delta P}{\mathrm{R}} \tag{1}$$

where Q - Flow rate; ΔP - Independent variable, the difference in pressure between the starting point (P_1), and the end of tube (P_2) can be controlled with the power of vacuum and using the tubing valves; R - Flow resistance for a circular-shaped tube, depends on the area of section (πr^2) and its length (L) with viscosity for different substances. In addition, resistance decreases with increasing cross-sectional area or decreasing length and it is in direct proportion to viscosity. For given calculation, the following equation (2) is used (Poiseuille's law):

$$\mathrm{R} = \frac{8\eta L}{\pi r^4} \tag{2}$$

For (2) equation, if (πr^2) and (L) are constant, the flow rate depends only on the difference between the vacuum pressure ($P_1 - P_2$) and the viscosity quality, equation (3):

$$\mathrm{Q'} = \frac{P_1 - P_2}{\eta} \tag{3}$$

Therefore, the selection of two constant values (maximum area of section and minimal length) is essential in the process of furnace design. The lower range of viscosity (η) could be achieved through temperature and vacuum.

The machine is needed to provide the following steps of processing (Fig. 2):

- Melting the polymer through the temperature in the reservoir, if its necessary (depending on raw material);
- Remove dissolved gases from molten substance, using the vacuum unit;
- Manage the vacuum circle to operate injection molding process;
- Adjust the drying process in the chamber with temperature;
- To apply a force on fused mass during the drying process.

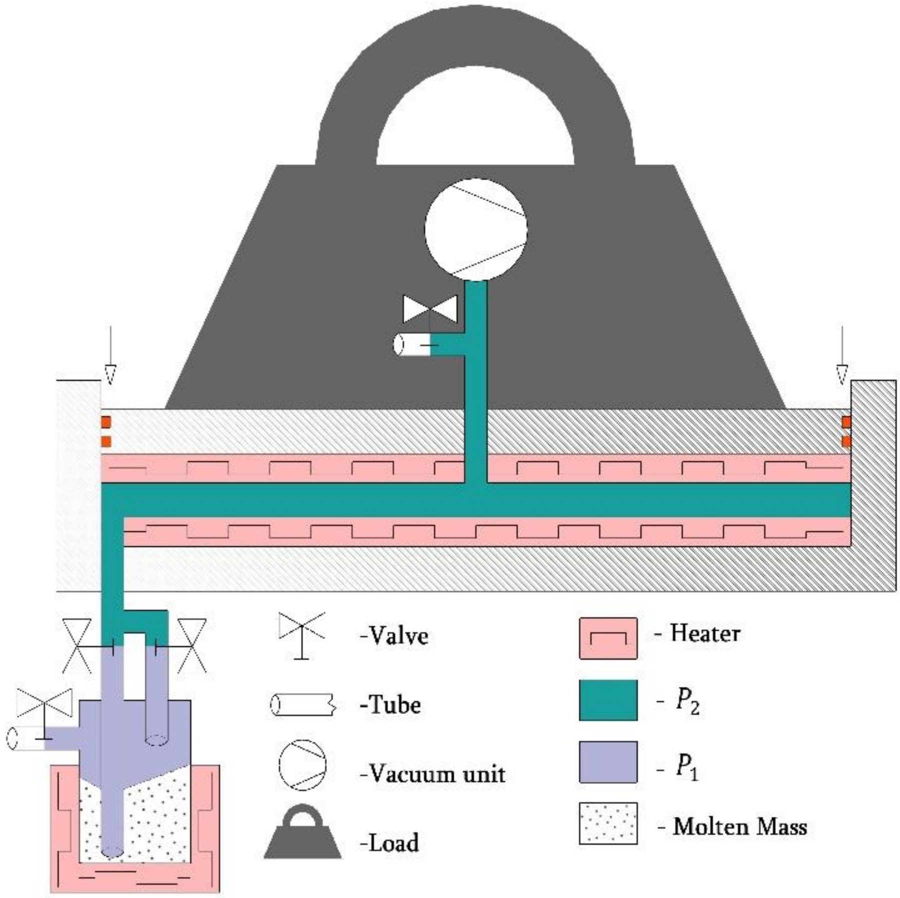

Figure 2. Schematic plane of operation process

Loads on beams, joint connections and heat dissipation is calculated using Finite Element Method. Vast majority of components have to be finished on CNC machine to easily achieve a proper tolerance and accuracy.

Conclusion

Ability of orienting the fibers in more dimensions creates objects that seek to avoid any specific weakness due to the unidirectional orientation of fibers. The properties of strength, flexibility and elasticity can also be magnified or diminished through the geometric shape and design of the final product. For example, ensuring proper wall thickness and creating multifunctional geometric shapes that can be molded as a single piece enhances the material and structural integrity of the product by reducing the requirements for joints, connections, and hardware [4]. FRP can be applied to strengthen the beams, columns [5]. With reaching the proper technical requirements, composite materials can be used to reduce high impact energy, as well as in the process of construction, automotive engineering, and sports equipment production.

Project and development of a machine is considered as a budget alternative to achieve proper physical and mechanical properties for composites, compare to high-cost vacuum furnaces with pressing capacity.

ვაკუუმ ღუმელი დაწნეხვის შესაძლებლობით

თამაზ ხმელიძე*, რევაზ სახვაძე**

**პროფესორი, საქართველოს ტექნიკური უნივერსიტეტი, სამშენებლო მანქანების დეპარტამენტი, თბილისი*

***დოქტორანტი, საქართველოს ტექნიკური უნივერსიტეტი, სამოქალაქო და სამრეწველო მშენებლობის დეპარტამენტი, თბილისი*

სტატიაში განხილულია ვაკუუმური ღუმელის პროექტი დაწნეხვის შესაძლებლობით პლასტმასისა და პოლიმერული კომპოზიტური მასალის მისაღებად და მათთვის სათანადო ფიზიკური და მექანიკური თვისებების მისაღწევად. მანქანის მთავარი უპირატესობა არის ვაკუუმ კამერაში სათანადო ნაერთების გამოყენება დამწოლი ძალისა და ტემპერატურის ერთდროულად მოქმედების პირობებში. კომპოზიტური მასალა არის მასალა, რომელიც მზადდება ორი ან მეტი შემადგენელი ელემენტისაგან. ამ შემადგენელ ელემენტებს აქვთ განსხვავებული ქიმიური და ფიზიკური ხასიათი და გაერთიანებულია ახალი თვისებების მქონე მასალის შესაქმნელად. კომპოზიციური მასალები ძირითადად გამოიყენება შენობებისთვის, ხიდებისთვის და ნაგებობებისთვის, როგორიცაა ნავის კორპუსები, საცურაო აუზების პანელები, სარბოლო მანქანების კორპუსი, საშხაპე სადგომები, აბანოები, შესანახი ავზები, იმიტირებული გრანიტი და კულტივირებული მარმარილოს ნიჟარები და საცობები. ტიპიური ინჟინრული კომპოზიციური მასალებია: რკინაბეტონი, კომპოზიციური ხე - „პლაივუდი", ბოჭკოებით არმირებული პოლიმერი, კერამიკული მატრიცის კომპოზიტები, ლითონის მატრიცის კომპოზიტები და სხვადასხვა კომბინაციები.

REFERENCES

1. Smallman, R. E., and R.J. Bishop, 1999 - Modern Physical Metallurgy and Materials Engineering. 6th ed. Oxford: Butterworth-Heinemann.
2. George Marsh, 8 October 2006 - 50 years of reinforced plastic boats, Way back Machine
3. David Donald 1995 - American Warplanes of World War II, Aerospace Publishing Limited, pages 251–252.
4. Erhard, Gunter. 2006 - Designing with Plastics, Trans. Martin Thompson. Munich: Hanser Publishers.
5. Naderpour, H.; Nagai, K.; Fakharian, P.; Haji, M, 1 May 2019 - "Innovative models for prediction of compressive strength of FRP-confined circular reinforced concrete columns using soft computing methods". Composite Structures. 215: 69–84.