STUDY REGARDING THE MECHANICAL BEHAVIOUR OF THE POLYMERIC COMPOSITES MATERIALS AT CRYOGENIC TEMPERATURE

Constantin POPESCU, Horatiu IANCAU, Liana HANCU, Alina CRAI[*]
**Departement Machine Building*
Technical University of Cluj-Napoca
Romania
e-mail:alinacrai77@yahoo.com

Abstract-In the present paper we propose the study of mechanical behaviour of the polymeric composites materials at normal and cryogenic temperature. We developed a comparative study of the mechanical characteristics obtained. The paper describes the results obtained from traction tensil strength and bending tensil strength. At the end of paper we give experimental results.

Keywords: *cyogeny, normal temperature, cryogenic temperature, cryostat*

1.INTRODUCTION

Cryogeny represents the ensemble of techniques used in the production, storage and utilization of liquefied gases. As a technology of producing and maintaining low temperatures, cryogeny uses all the domains of modern science and head (top) techniques, being used both in research and production. By low temperatures we refer to the 120-20K domains where the term "cryogeny" is an adjective used in the characterization of technique and scientific activities, which take place under 120K. The cryogenic applications in engineering consist in the concrete usage of the physical phenomena related to low and very low temperatures.

The polymeric composites with organic matrix emerged and developed after 1900.

In 1940, polymeric composites reinforced with fiberglass were obtained. Henry Ford proves the possibility and the advantage of using composite materials in the automobile industry.

The composites scale improved once the unsaturated polyesters were discovered in the year of 1942.

American Cyanamid Co. and Plascon Co. produced the first unsaturated polyester resins between 1943 and 1944.

In the 80s,a series of composite materials called "of second generation or "high performance" were developed, based on epoxy resins reinforced with fiber glass, carbon or Kevlar, which offered a series of special particularities and advantages.

While in the year of 1985, the global composites production was approximately of 2.3 million tons, in 2000 it raised over the number of 10 million tons.

The industrial production of the polymeric composites developed rapidly, polymeric composite materials entered the most various domains of techniques.

Today, a lot of reinforcing materials, organic matrix and auxiliary materials are known, while through their combination one can obtain polymeric composites capable of facing the most exacting requests.

Composite materials are the first materials of which the internal structural display is conceived by the human being, not only in their molecular enhancement, but offering them favorable resistance to particular directions of stress.

Thus, the new materials obtained are heterogeneous and strongly anisotropy.The technological progress of the composite materials had been intense, so that in the present time engineers benefit of a large scale of modern composites reinforced (based) with fiber glass, carbon or Kevlar, which compete, from the mechanical point of view, with the best steels, ferrous and not ferrous alloys.

Regarding the scientific research, multi-discipline is imposed, the studying of polymeric composites requiring entry dates from several scientific branches as chemistry, physics, mathematics, mechanics and engineering.

The polymeric composites, reinforced with elements of fiber glass, carbon, boron, copper fibers, quartz, in a multiple variety, had invaded all the domains of the productive activities, taking the place, constantly and in a more and more significant manner, of whole categories of classical materials such as wood, glass and metals. Having a low weight, being thermo-insulator, resistant to corrosion and radiations, easy to process (work), these composite materials have superior mechanical properties to those of the regular plastic materials. Only the temperature domains on which they can be used limit their utilization.

Plastic materials are macromolecular materials – chemical substances with a high molecular mass – obtained through the polymerization process.

By the condensation reaction specific to the thermal-rigid plastic materials, the acquirement of the new product, condensation resin by mean, is accompanied by the separation of several auxiliary products, water, in most of the times. The condensation resin has a bigger molecule than the molecules of the initial components, and the elementary composition of resin always differs from the composition of the initial substances.

The polymerization reaction specific to the thermoplastic materials is a chemical process of forming a new substance through the combination of molecules of same composition in a molecule with high molecular weight. The initial molecule is called monomer, while the new-formed molecule is called polymer. In the polymerization reactions no separation between the auxiliary products takes place. Through this particularization the polymerization reaction strongly differs from the condensation reaction.

Plastic material can be entirely made from polymers (polyethylene, polyester, polypropylene), in this case the denomination of the plastic material and the denomination of the polymer also coincide, while the physical-chemical characteristics and the technical importance of the plastic material depend entirely on the chemical composition and the structure of the polymer.

The properties of the plastic materials may vary according to the environment of utilization, loading duration, loading types (categories), components configuration, and temperature.

Figure 1 presents the temperature addiction of different type of no reinforced plastic materials

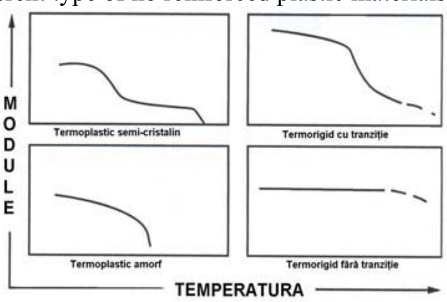

Figure1:Mechanical characteristics of different no reinforced plastic materials.

Standard mechanical properties are usually obtained through testing methods specified by The American Standards of Testing Materials (ASTM) or by the International Standards Organization (ISO).

The characterization of the mechanical properties of the polymeric composites covers both the correct dimension of the finite products and the anticipated knowledge of their conduct in the process of current exploitation.

The specific properties of the polymeric composites alter sensitively along with the temperature. Unlike the crystalline substances, where under the influence of the temperature raise, the transition from the solid state to the liquid state at a certain temperature is suddenly made, in the case of the polymeric composites this transition takes place gradually in a whole domain of temperature. This phenomenon represents a big step in the composite products exploitation.

The thermical and thermo mechanical properties of the polymeric composites may be slightly influenced by a series of factors as the filling agents (kaolin, chalk), reinforcing agents (glass, asbestos, metals), stabilizers and plastics.

The mechanical properties of the plastic masses with filling materials depend considerably on the properties, quantity and orientation of the filling fibers. The fluoric plastic is a proper material regarding the resistance to cold; it is used successfully up to very low temperatures.

The *getinax* and the *textolit* are used in cryogenically devices as thermic sealing and isolating materials.

Plastics reinforced with fiberglass are the most perspective materials for the cryogenic technique, which, from the point of view of resistance, approaches steels.

2.THE MECHANICAL BEHAVIOR OF COMPOSITE MATERIALS

The mechanical properties of some plastic materials reinforced on low temperatures are presented in Table 1.[9]. As shown in the table below, for the 3 composite materials, *textolit*,_*getinax*, and *sticlatextolit*, the traction stretch resistance raises significantly on the liquid nitrogen temperature besides the room temperature (239K).

The characteristic of deformation, or toughness, is diminished once the temperature reduces.

On low cryogenic temperatures, most of the composite materials become more fragile, so their tenacity reduces. The behavior of the composite materials on low temperatures is similar to the one of metals.

The kind label of the material	The mechanical charac teristics	U.M.	Temperature [K]	
			293	77
Textolit	Rp 0,2	N/mm^2	85	106
	Rm	N/mm^2	167	310
	K C U	KJ/m^2	28,4	14,7
Getinax	Rp 0,2	N/mm^2	74	86
	Rm	N/mm^2	142	328
	K C U	KJ/m^2	26,8	18,1
Sticlotexto lit	Rp 0,2	N/mm^2	144	256
	Rm	N/mm^2	78	176
	K C U	KJ/m^2	146	172

Table 1:The mechanical characteristics of some reinforced plastic materials on low temperatures

The behavior of the materials used in the construction of finite products is made under different conditions of testing and request. The conditions under which the testing of materials is made may be very numerous, approaching, more or less, the laboratory experimentation to reality (the real situation), being conventionally established and some of them getting standardized.

The behavior of the polymeric composites specific to temperature exists due to the energetic variation of the valence relations. This energy value depends directly on the molecular mass and the molecular mass distribution, being larger in the case of a larger grade of polymerization, and being smaller in the case of a small grade of polymerization.

The knowledge of the polymeric composites behavior in the conditions of thermic or thermo mechanic pressure (request) is very important, so that their thermic properties is quantified determined.

The mechanical testing on low temperatures is made in the same way as in the case of environmental temperature (the specimen (piece test) deforms progressively at a constant deformation speed, or in some cases at a constant loading speed).

The distinction is made by the fact that the specimen cools initially at the desired temperature and eventually maintains the same temperature, in precise prescribed limits, during the whole duration of testing, Figure 2.[9]

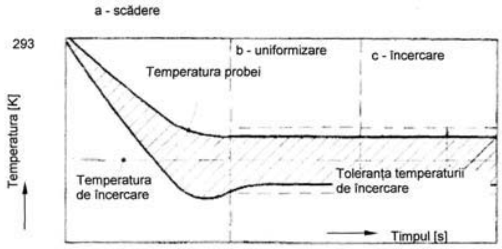

Figure 2:The cooling diagram of the specimen (piece test) in cryostat, for the mechanical tests under cryogenic conditions

The cooling of the specimen (piece test) is made at a temperature equal to the test temperature in an enclosure called "cryostat" This rule is valid especially when specimens are hold in the cooling medium during the whole duration of the testing. For the specimens of reduced dimensions, which are loaded outside the cooling installation, for instance the toughness specimens, some norms impose their cooling at temperatures inferior to the ones of the testing, according to a difference of 1 K for each step of 10 K between the environmental temperature and the testing temperature (STAS 6834-75).

When the handling of the cooled specimen outside the cooling installation is necessary, the norms bring certain specifications on the period of time between the draw of the specimen out of the cooling medium and the testing. This period of time is limited to 5 seconds in the case of small specimens, with a thickness up to 10 mm, for instance the specimen meant for traction testing or shock bending, and up to 15 seconds in the case of specimen of 16-25 mm thickness, for instance the specimen loaded with soldering for shock bending testing. (STAS 961-81)

The cooling system is made by the means the controlled cooling of a specimen is made in the case of it's testing in low temperature conditions, by that one can understand: the cooling medium, the means of temperature measurement, the cooling installation.

The determination of the mechanical characteristics of the materials in cryogenic conditions is made on universal machines designed for mechanical testing on which the cryostat is set for the cooling of the specimens. The parameters of the testing machines are chosen depending on the kind of testing that is to be made, the maximum provided load, the size of the specimen, the desired precision.

The most non-metallic materials used in the cryogenic technique are the plastic materials.

Considering their mechanical properties, plastic materials can be divided in three groups of resistance: low – polyethylene, polystyrene, *aminoplaste, medium-kapron, (polyamides – policaprolactama), textolit, genitax,* *(fenolformaldehidice resins), polyamides, azbotextolitul, high – glass plastics, glass volocnit, (resins phenol – formaldehydes), steclotextolit (phenol resins).*

Once the temperature decreases, most of the plastic materials raise their resistance and hardness and reduce their plasticity and toughness.

The conventional feature of the standard mechanical testing performed on specimens make that, in some situations, direct testing of the real pieces to be necessary.

The study of the mechanical characteristics of the materials on low temperatures is necessary to be performed minding certain domains of metal and non-metal materials such as chemistry industry, aeronautic industry, and food industry.

The testing of the materials bring other difficulties into different points of a tool, due to the lack of homogeneity of the properties, the dispersion of these values among the unavoidable diversions of the componence process and the testing conditions.

In Table 2.(a,b), there are presented the traction testing and the bending results performed at normal and low temperatures. The materials (resin, talc powder, quartz) have different reinforcement degrees.

	The material	Traction tensil strength $\sigma_{rt,\ MPa}$	
		293 K	77 K
1	No reinforced resin	72	93, 1
2	resin +20% talc	45,3	101,79
3	resin+33,3% talc	59,15	97,44
4	resin+42,8% talc	51,3	97,98
5	resin +50% talc	38,17	54,06
6	resin+43% cuart	62,9	122,4
7	resin+50% quartz	-	-
8	resin+55,5% cuart	64,7	112,2
9	resin+60% quartz	54,9	100,3
10.	resin+67% quartz	59,1	97,4

Table 2:Traction tests(a)

	The material	Bending tensil strength $\sigma_{r\hat{i},\ MPa}$	
		293 K	77 K
1	No reinforced resin	93,1	147,6
2	resin +20% talc	127,8	217,3
3	resin+33,3% talc	-	-
4	resin+42,8% talc	109,2	205,6
5	resin +50% talc	76,4	114,1
6	resin+43% quartz	-	-
7	resin+50% quartz	104,9	150,6
8	resin+55,5% cuart	-	-
9	resin+60% quartz	103,2	175,9
10.	resin+67% quartz	104,4	181,3

Table 2.Bending tests (b)

Analyzing the results from Table.2 results that in all cases of traction and bending the tensil strenght raises at the liquefied natrium temperature (77k) besides the room temperature (293K). A more interesting variation represents the bending tensil strenght depending on the quartz percentage (fig3) and the talc powder percentage (fig.4) on both the temperature levels already tested**.**

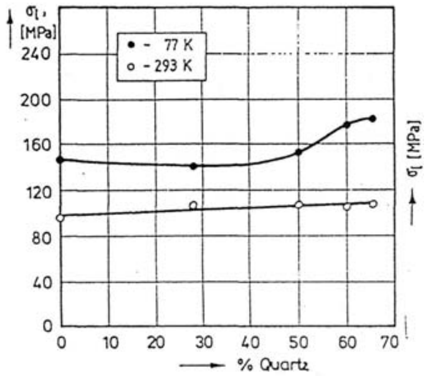

Figure.3: Variation of traction tensil strenght at bend in function of quart percentage

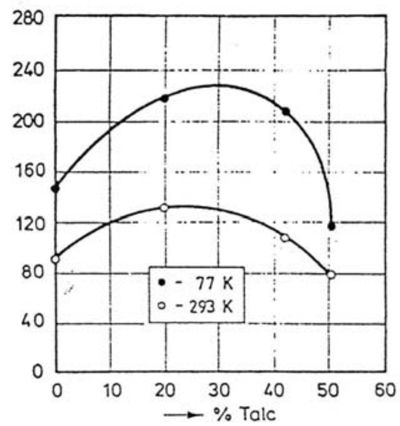

Figure.4: Variation of traction tensil strenght at bend in function of talc percentage

We may notice that in the case of the composites based on talc powder, at a percentage of 20 and 30 %, the curves present a maximum both at 293K and 77K.

The mechanical testing on low temperatures contains: the resistance testing, toughness, relaxation, tiredness, and flows. For making a comparison between the behaviors of different materials in different testing conditions, these testing have to be realized in the same conditions and with the same shapes of the specimen. These proved that the most majority of the testing procedures must be standardized.

3. CONCLUSIONS

- In the present time, the plastic materials and the polymeric composites are in the full process of development, recording great raising levels, that being the reason of a good knowledge of the mechanical and technological behavior of these materials on cryogenic temperatures. Below certain temperatures most of these materials become fragile and so they are not recommended to overtake continuous or random mechanical requests. It is necessary to establish the materials, which keep o sufficient tenacity on cryogenic temperatures, and to perform and develop new materials called cryogenic materials, which can be used, on these temperatures.
- It is necessary to be aware of the mechanical behavior of the composite materials on low temperatures for replacing the classic materials, the traditional ones, with polymeric composites, which have superior advantages.
- The mechanical and physical characteristic of the polymeric composites is quite difficult at the moment because of the plenty parameters which have to be taken into consideration for expressing the response of the material in different conditions of request.
- The physical and mechanical conditions depend on surrounding factors (temperature, humidity, chemical agents), on the testing parameters (the type of request, request directions, loading speed), on the conditions of the obtainance of the material (pressions, temperatures, add materials), and of course on the reinforcement grade.
- The mechanical properties of the polymeric composites depend on the molecular units, which form the net respectively on the length and density of the bindings.
- From the studied specialty literature, results that up to the present the polymeric composites have been studied more or less on low temperatures.

References

[1] D. Gay, *Materiaux composites,* 4^e edition revue et augmentee, Hermes, Paris, 1997;

[2] L. Hancu., H. Iancău, G.Achimaş, *Criogenie şi maşini frigorifice,* Editura Alma Mater Cluj-Napoca, 2003;

[3] G. Hubca, *Materiale compozite,* Editura Tehnică, Bucureşti, 1999;

[4] A. Iacobescu, *Materiale compozite, ceramice, minerale şi sinterizate, procedee şi tehnologii de prelucrare,* Editura Tehnică, Bucureşti, 2001;

[5] H. Iancău, O. Nemeş, *Materiale compozite – concepţie şi fabricaţie*, Editura Mediamira, Cluj – Napoca, 2003;

[6] Şt. Ispas, *Materiale compozite,* Editura Tehnică, Bucureşti, 1987;

[7] M. Mihalcu, *Materiale plastice armate,* Editura Tehnică, Bucureşti, 1999;

[8] A. Nanu, A. Mărcuşanu, *Tratat de tehnologii neconvenţionale – Prelucrarea materialelor neconvenţionale,* Editura Artpress, Bucureşti, 2000;

[9] I. Tapalagă, P. Berce, H. Iancău, T. Cherebeţiu, G. Achimaş, G. Vermeşan, *Criogenia în construcţia de maşini,* Editura Dacia Cluj-Napoca, 1988

[10] C. Popescu,Stadiul actual al comportarii mecanice la temperatura ambianta si la temperaturi scazute, a materialelor compozite polimerice, Referat Nr.1 de doctorat UTC-N, iulie, 2006

[11] C. Alina, P. Teodor, I. Horatiu, *Mathematical modelling of the flow of composite materials with short fibers,* 10t h International Research/Expert Conference Trends in the Development of Machinery and Associated Technology"TMT 2006, Barcelona-Lloret de Mar, Spain, 11-15 September