Rheological Behaviour of Copolymer Stamylan P108 MF used in Bumper Structure from Automotive Industry

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In the research paper we present a study regarding the road traffic safety and the ageing phenomenon of vehicle bumpers. For our study we used the accelerated ageing in conventional environment which is the most complex and comprehensive method to determine the bumper ageing. This method is used for plastic materials and comprehends ageing methods which simulates the natural exposes: taking into account the temperature, humidity and the presence of some chemicals, oils and fuels. Also, the method consists in the ageing of plastic materials which initially were conditioned in climatic chamber. The final evaluation happens when the object we study is tempering to the ambient temperature in the same climatic chamber (T = 23°C ± 2°C , UR = 50% ± 5%).

Keywords: ageing, strength depreciation, stress, strain, rheology, fracture

The automotive industry uses engineered polymer composites and plastics in a wide range of applications, as the second most common class of automotive materials after ferrous metals and alloys (cast iron, steel, nickel) which represent 68% by weight; other non-ferrous metals used include copper, zinc, aluminium, magnesium, titanium and their alloys. The plastics contents of commercial vehicles comprise about 50 % of all interior components, including safety subsystems, door and seat assemblies. During the enormous growth of plastics components in automotive, the advantages of using plastics have changed [1, 2]. Mounting costs are being met by the ability of plastics to be moulded into components of complex geometries, often replacing several parts in other materials, and offering integral fitments that all add up to easier assembly. Many types of polymers are used in more than thousand different parts of all shapes and sizes. A quick look inside any model of the car shows that plastics are now used in exterior and interior components such as bumpers, doors, safety and windows, headlight and side view mirror housing, trunk lids, hoods, grilles and wheel covers. Although up to 13 different polymers may be used in a single car model, just three types of plastics make up some 66 % of the total plastics used in a car: polypropylene (32 %), polyurethane (17 %) and PVC (16 %) [3, 4].

Bumpers are safety features fixed to the front and back of vehicles. They are design to take a certain amount of impact from a collision by acting as dampers. To improve efficiency and performance modern bumpers are design to be aerodynamic and cheap [2, 4]. By developing wind channels in the bumper air can be used to provide more grip and stability for a safer drive. Modern bumpers are also designed to be interchangeable after impacts for low cost repair. Car manufactures tend to design their bumpers from thermoplastics as it is cheaply made and adsorbs impacts more effectively [5, 6]. Since metal components were more used in the design of larger vehicles a polymer based material was selected [7 - 9]. This allowed for cheaper and easier manufacture components. After researching different polymers and comparing mechanical properties it was found that mainly are used these materials:

PP – polypropylene is extremely chemically resistant and almost completely impervious to water. Black has the best UV resistance and is increasingly used in the construction industry. Application: automotive bumpers, chemical tanks, cable insulation, battery boxes, bottles, petrol cans, indoor and outdoor carpets, carpet fibres.

PC – polycarbonate has good weather and UV resistance, with transparency levels almost good as acrylic. Applications: security screens, aircraft panels, bumpers, spectacle lenses, headlamp lenses.

PBT – polybutylene terephthalate has good chemical resistance and electrical properties, hard and tough material with water absorption, very good resistance to dynamic stress, thermal and dimension stability. Easy to manufacture - fast crystallization, fast cooling. Application: fog lamp housings and bezels, sun-roof front parts, locking system housings, door handles, bumpers.

ABS – acrylonitrile-butadiene-styrene is a durable thermoplastic, resistant to weather and some chemicals, popular for vacuum formed components. It is a rigid plastic with rubber like characteristics, which gives it good impact resistance. Application: car dashboards, covers, bumpers.

PS – polystyrene is very popular, ease to manufacture, but has poor resistance to UV light. Application: equipment housings, buttons, car fittings, display bases, bumpers.

Experimental part

Materials and method

Experimental Set-up

To determine the rheological behavior of copolymer P108 Stamylan MF, specimens with dimensions of 4 mm x 10 mm x 50 mm were prepared. In the first stage of the experiment, specimens were tested in their original condition at tensile stress, determining the maximum stresses (σ_{max}), fracture stresses (σ_r), strain ($\varepsilon_{\sigma max}$) and fracture strain (ε_r).

In the next step, samples were subject to cycles characterized by: negative and positive temperature variations, different durations of treatment, relative humidity and different aggressive factors (chemical

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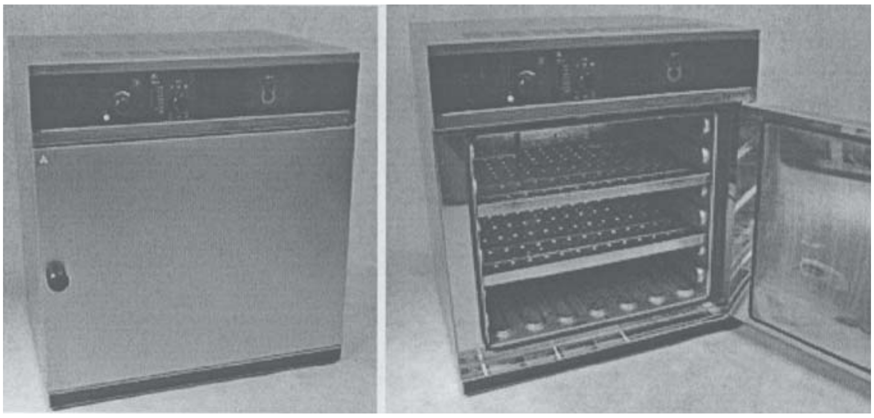

Figure 1. MEMMERT UL 500

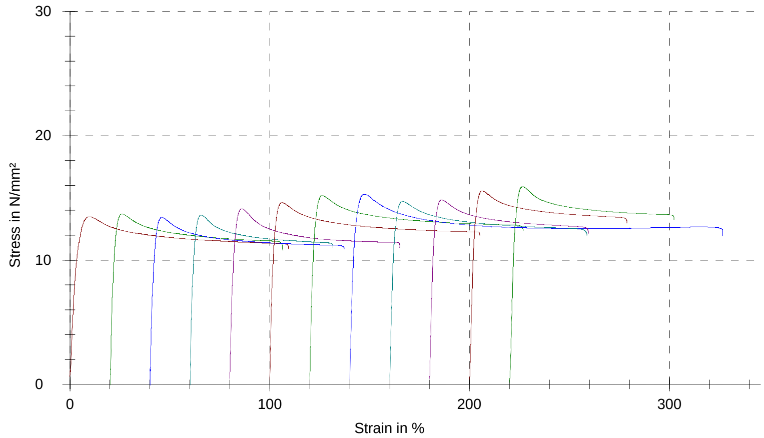

Fig. 2. Stress – strain curve of Stamylan P108 MF for initial conditions of samples

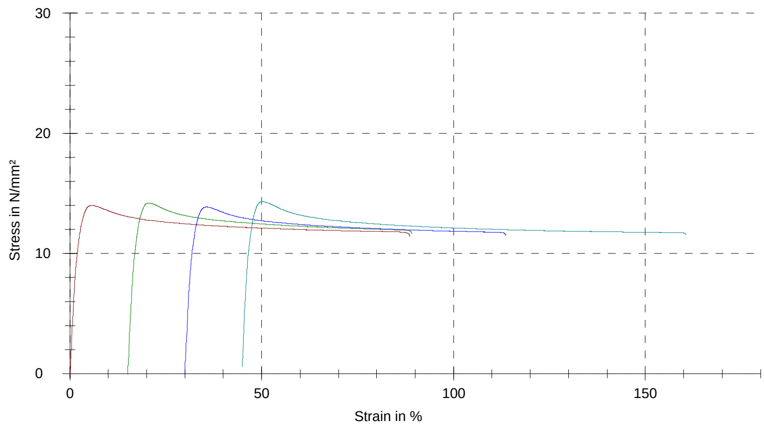

Fig. 3. Stress – strain curve for samples immersed in Bacford device during 7 days at 40°C, relative air humidity UR=95%

agents). This copolymer ageing methods duration is multiple of 24 h and assumes:

Case 1 - Stamylan P108 MF t=7 days at temperature T= - 30°C;

Case 2 - Stamylan P108 MF t=14 days at temperature T= - 30°C;

Case 3 - Stamylan P108 MF t=7 days at temperature T= +40°C, relative air humidity UR=95%, in immersion device type Bacford;

Case 4 - Stamylan P108 MF t=14 days at temperature T= + 40°C, relative air humidity UR=95%, in immersion device type Bacford;

Case 5 - Stamylan P108 MF t=7 days at temperature T= + 70 °C;

Case 6 - Stamylan P108 MF t=7 days at temperature T= + 70 °C in braking fluid DOT4;

Case 7 - Stamylan P108 MF t=7 days at temperature T = + 85 °C;

Case 8 - Stamylan P108 MF t=14 days at temperature T= + 85 °C;

Case 9 - Stamylan P108 MF t=7 days at temperature T= + 100 °C

Case 10 - Stamylan P108 MF t=7 days at temperature T= + 100°C immersion in GLACEOL coolant type D50/50;

Case 11 - Stamylan P108 MF – occasional contact with diesel fuel EURO 3 and expose of UV lamp, t=500 h;

Case 12 - Stamylan P108 MF, material from the bumper after rolling t=6 months.

After the end of ageing cycle the oven will be brought back at the ambient temperature in the climatic chamber between 2-4 or 24 h and determine:

a) for the measurable characteristic:

- absolute values after the ageing;
- relative variation in ratio with the initial values.

b) for the immeasurable characteristic:

- observed modifications.

For the ageing of check bar or other pieces we used the ageing – oven type *MEMMERT UL 500* that can be seen in figure 1 [2, 6].

Results and discussions

For each case of stresses and rheological condition minimum 5 samples were tested. After tensile testing of specimens subject to different treatments, resulting stress

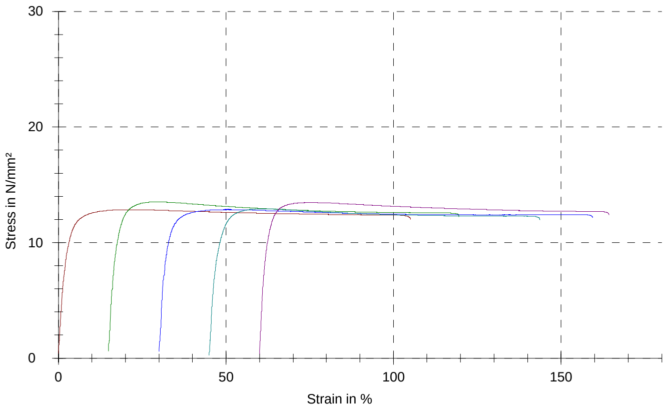

Fig. 4. Stress – strain curve after occasional contact with diesel fuel EURO 3 and expose of UV lamp during 500 h

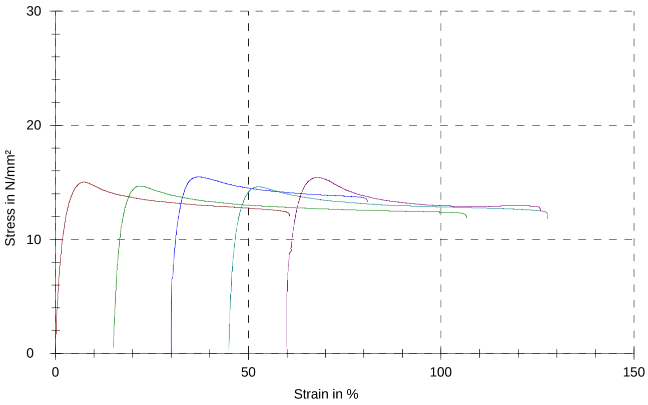

Fig. 5. Stress – strain diagram after rolling 6 months

Table 1
AVERAGE VALUES OF MAIN RESULTS IN TERMS OF MAXIMUM STRESSES (σ_{max}), FRACTURE STRESSES (σ_r), STRAIN ($\varepsilon_{\sigma max}$) AND FRACTURE STRAIN (ε_r) FOR ALL TREATMENTS CASES

Cases	Treatments parameters	Average values					
		σ_{max} [MPa]	σ_r [MPa]	σ_{max}/σ_r	$\varepsilon_{\sigma max}$ %	ε_r %	$\varepsilon_r/\varepsilon_{\sigma max}$
0	Initial condition T=22°C; UR=67%	14,523	11,721	1,239	6,576	99,00	15,053
1	t=7 days; T= -30°C	15,190	12,462	1,218	6,142	102,50	16,688
2	t=14 days; T=-30 °C	14,250	11,732	1,214	5,330	96,24	18,056
3	t=7 days; T= 40°C UR=95%, in immersion	14,090	11,498	1,225	5,452	82,4	15,113
4	t=14 days; T=40°C, UR=95%, in immersion	14,784	12,400	1,192	5,524	97,52	17,655
5	t=7 days; T=70 °C	14,284	11,88	1,202	5,652	129,08	22,837
6	t=7 days; T=70 °C in braking fluid DOT 4	14,220	11,533	1,233	6,523	84,80	12,999
7	t=7 days; T=85 °C	14,994	12,788	1,172	6,058	104,47	17,244
8	t=14 days; =85 °C	13,934	11,758	1,185	5,494	82,84	15,078
9	t=7 days; T=100 °C	14,322	12,61	1,135	5,728	126,76	22,129
10	t=7 days; T=100°C immersion in GLACEOL coolant type D50/50	15,502	13,694	1,132	6,250	101,12	16,179
11	contact with diesel fuel EURO 3 and expose of UV lamp – 500 hours	13,100	12,122	1,080	17,590	108,38	6,161
12	Material of bumper after rolling 6 months	15,024	12,272	1,224	7,444	70,32	9,446

strain curves. In figure 2, it can be noticed elastic behaviour, the plastic deformation and ultimate tensile stresses for all tested samples in initial conditions. Due to composite structure of copolymer P108 Stamylan MF used for bumper manufacture, it can be noticed a little dispersion of stress and strain values. In figure 3, the stress-strain curves for samples immersed in Bacford device during 7 days at 40°C, relative air humidity UR=95% are presented. Because of treatment of samples at temperature of 40°C and relative air humidity UR of 95%, it can be observed that the deformations generated by creep are very large compared with initial state of specimens. A similar rheological behaviour is observed for UV exposure and contact with diesel fuel EURO 3 (fig. 4). In table 1 are presented the average values of maximum stresses (σ_{max}), fracture stresses (σ_r), strain ($\varepsilon_{\sigma max}$) and fracture strain (ε_r).

Figure 6 shows the variation of normal stress determined experimentally for each treatment of specimens. It can be noticed that the fracture stresses are lower than maximum stresses. During experiments, specimens reach a maximum stress (σ_{max}), and breaking occurs at a lower stress – fracture stress (σ_r), due to changing cross section. It was found that the ratio of the maximum and fracture stress in all analyzed cases have similar values , ranging between 1.08 and 1.23, according to table 1.

Figure 7 presents comparative values of fracture stresses, observing that the maximum values were obtained for: case 1 (t=7 days; T= -30°C), case 4 (t=14 days; T=40°C, UR=95%, in immersion), case 7 (t=7 days; T=85 °C), case 9 (t=7 days; T=100 °C), case 10 (t=7 days; T=100°C immersion in GLACEOL coolant type D50/50) – all samples being thermally treated.

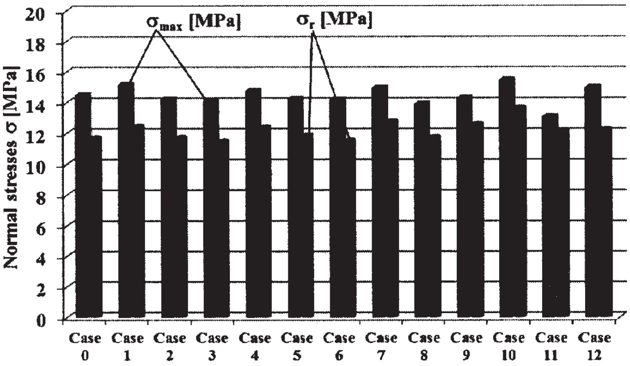

Fig. 6. Variation of maximum stresses (σ_{max}), fracture stresses (σ_r)

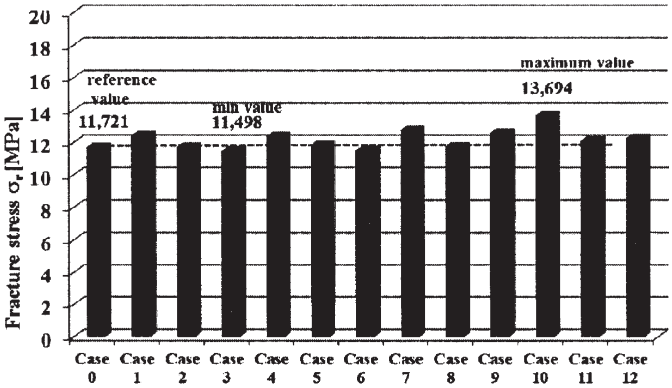

Fig. 7. Minimum versus maximum values of fracture stresses compared with reference value

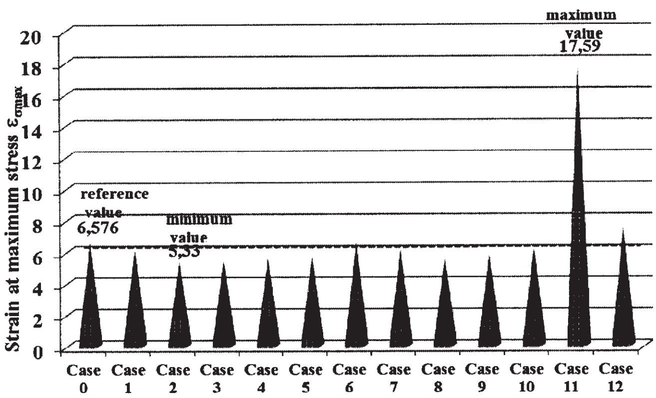

Fig. 8. Comparative values of strain for all tested case

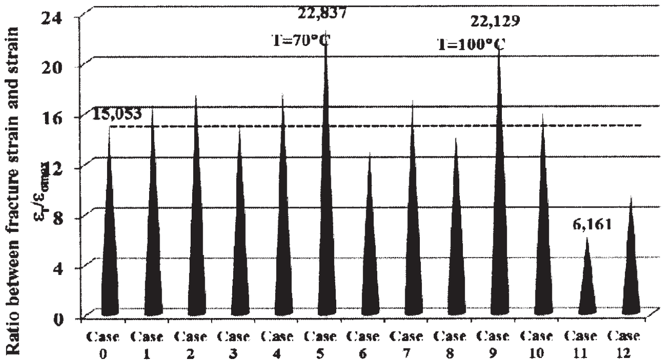

Fig. 9. Comparative values of ratio between fracture strain and strain

Regarding deformation (fig. 8), it was noticed that the maximum deformation was obtained in case of ultraviolet (UV) exposure combined with occasional contact with diesel fuel ($\varepsilon_{\sigma max}$ = 17.59 %). The minimum value of strain was recorded by samples tested during 14 days at -30°C.

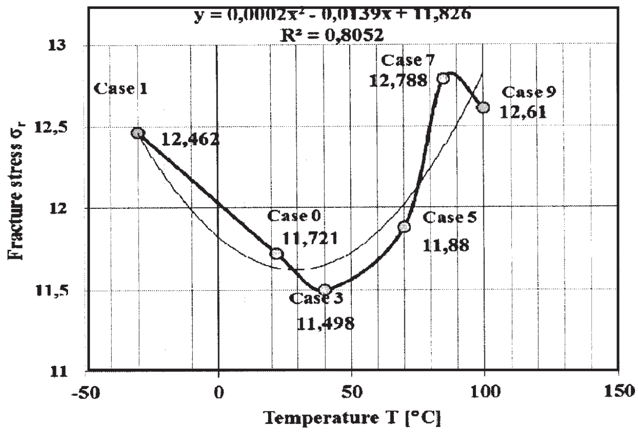

Fig. 10. Variation of fracture stress versus temperature

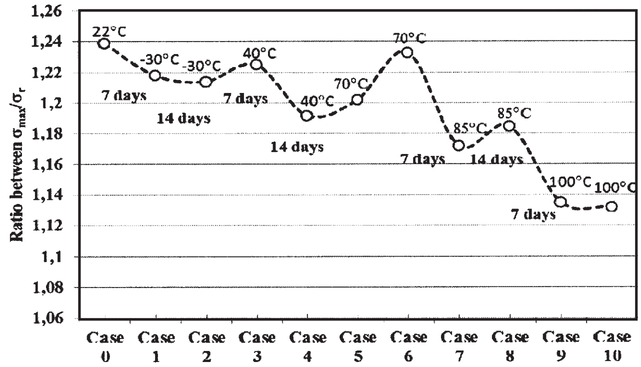

Fig. 11. Decreased variation of ratio between maximum stresses and fracture stresses

In figure 9 it is shown the ratio between fracture strain (ε_r) and specific deformations at maximum stresses ($\varepsilon_{\sigma max}$). It is found that MF Stamylan P108 copolymer material behaves differently in terms of flow duration, depending on the treatment. Thus, there are two temperature thresholds (70 and 100°C) in which the duration of the deformation is longer and partly due to the chemical reactions that occur in the matrix of the composite.

Analyzing curve from figure 10, it is found that fracture stresses vary with temperature according to the parabolic law and is rising with increasing temperature (negative or positive).

An interesting phenomenon can be noticed i.e. variation is the ratio of the maximum and breaking stresses for each studied cases. Thus, the fracture stresses varied between 0.9 and 1,1. It can be appreciated that the tensile strength after various treatments, does not change.

With increasing temperature, there are large plastic deformations and rupture tends to occur in a very short time after the maximum stresses appeared (fig. 11).

Conclusions

For the same duration of tests with dry temperature increasing will have a negative effect when temperature is over 100°C, but this temperature is not specific for the vehicle exterior components as we have in our case the bumper.

For this kind of material, the heat aging at the same temperature does not affect negatively the physico-mechanical characteristics only in the case when the duration condition is longer than 14 days.

The ageing at negative temperature -30°C affects material elasticity by the increasing of breaking elongation without depreciating the traction characteristics.

Reffering to the occasional fluids with which come into contact the material assessable negative effects have been pointed out better towards the windshield washing liquid, diesel fuel EURO 3 and oil affecting its elasticity (with decreasing of traction characteristics).

With the aging phenomenon of vehicle bumpers material their properties are decreasing so a lower safety results which can affect the absorption energy. That is why studying different kind of materials is important to be sure that you have chosen the best one.

In conclusion, the different treatment of the copolymer specimen affects the maximum stress and deformation at the break, but does not influence overall strength of the material. Basically, the bumper withstands under environment variations, but the deformations occurring may adversely affect aesthetics and connections with other parts.

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