

Some functional properties of composite material based on scrap tires

Research Article

Renate Plesuma^{1*}, Laimonis Malers¹

¹ Department of Polymer Materials Technology, Riga Technical University, Azenes street 14/22, LV 1048, Riga, Latvia

Received 20 March 2013; accepted 16 June 2013

Abstract: The utilization of scrap tires still obtains a remarkable importance from the aspect of unloading the environment from non-degradable waste [1]. One of the most prospective ways for scrap tires reuse is a production of composite materials [2]. This research must be considered as a continuation of previous investigations [3, 4]. It is devoted to the clarification of some functional properties, which are considered important for the view of practical applications, of the composite material. Some functional properties of the material were investigated, for instance, the compressive stress at different extent of deformation of sample (till 67% of initial thickness) (LVS EN 826) [5] and the resistance to UV radiation (modified method based on LVS EN 14836) [6]. Experiments were realized on the purposefully selected samples. The results were evaluated in the correlation with potential changes of Shore C hardness (Shore scale, ISO 7619-1, ISO 868) [7, 8]. The results showed noticeable resistance of the composite material against the mechanical influence and ultraviolet (UV) radiation. The correlation with the composition of the material, activity of binder, definite technological parameters, and the conditions supported during the production, were determined. It was estimated that selected properties and characteristics of the material are strongly dependent from the composition and technological parameters used in production of the composite material, and from the size of rubber crumb. Obtained results show possibility to attain desirable changes in the composite material properties by changing both the composition and technological parameters of examined material.

Keywords: Scrap tires • polyurethane binder • composite material • resistance to environmental impact

© Versita sp. z o.o.

1. Introduction

One of the most prospective ways for the reuse of scrap tires is the production of composite materials [2, 9]. The present research must be considered as the continuation of previous investigations [3, 4]. The paper is devoted to the clarification of some important properties of the composite material from the aspect of its practical application.

The material produced can be used in a wide range of applications, for example, in the production industry, – as the absorbent of the mechanical vibrations, in the road industry, – as the protective barriers, in the building industry, – as the sound insulating and damping material [9]. The composite material can be used as the damping material in upper layer of children playgrounds or in sports industry as the synthetic surfaces for outdoor sports areas [6, 9]. The selected properties of the composite material such as compressive stress at different extent of deformation and the resistance to UV radiation, were investigated, in order to find out the behavior of the composite material in

*E-mail: renate.plesuma@gmail.com

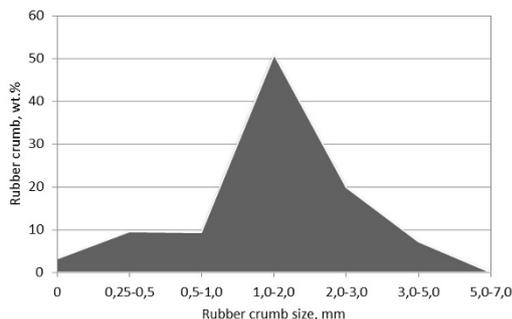


Figure 1. The particle size distribution of non-fractionated rubber crumb

the specific kind of environmental conditions, such as continual compressive loads and *UV* radiation. The goal of this paper is to investigate the resistance of the composite material against the mechanical influence at different extent of deformation of samples in the compressive mode of loading and to examine the *UV* radiation resistance of the composite material. Special attention was devoted in order to find out the correlation between the composition of the material (binder content), the activity of the binder (reactivity of the binder), definite technological parameters (relative air humidity *RH*) and conditions supported during the production of the material samples (formation temperature *T*, formation pressure *P* and formation (exposure) time), and Shore *C* hardness of the composite material.

2. Materials and investigation methods

In this work non-fractionated and fractionated scrap rubber crumb was used in order to produce samples of the composite material. The particle size distribution of non-fractionated rubber crumb was determined by the modified Sieve method based on LVS EN 933-1 (stack of 0.25, 0.5, 1, 2, 3, 5, 7, 10 mm sieves) [10], as it is shown in Figure 2.

The specimens of the composite material (dimensions 60×80×20 mm) were prepared by the mechanical mixing of scrap rubber crumb with the polymer binder at different formation conditions – temperature *T* ($T_a = 17 - 20^\circ\text{C}$, 40°C and 75°C) and pressure *P* (0.004, 0.008 and 0.02 MPa). The hardening of polyurethane binder is highly dependent of the quality of reaction between isocyanate groups and hydroxyl groups, which are involved in the material through the environment's moisture during the production

Table 1. The Results of Shore *C* hardness for specimens prepared from fractionated rubber crumb ($T_a = 17 - 20^\circ\text{C}$, $P = 0.004$ MPa)

Fraction size, mm	Binder content (- NCO 2.4%), wt. %	Shore <i>C</i> Hardness (after 24 h)	Changes (%) in Shore <i>C</i> Hardness after 7 days
>0.25<1	13	46	-4
	18	46	-5
	23	52	-3
>1<2	13	50	-5
	18	50	-4
	23	53	0
>3<5	13	51	-3
	18	51	-8
	23	48	-6

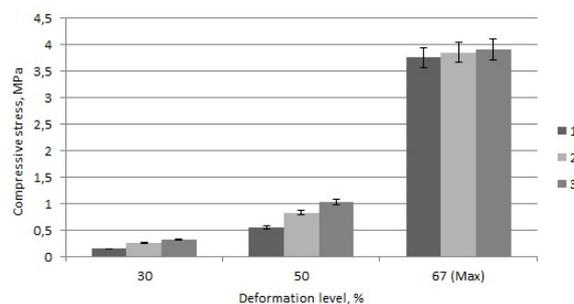


Figure 2. Variation in compressive stress with polymer binder's (-NCO 2.4 %) content (1- 13 wt.%; 2-18 wt.%; 3- 23 wt.%) and different deformation levels of composite material (formation conditions: $T_a = 17 - 20^\circ\text{C}$; $P = 0.004$ MPa).

of the composite material [11]. In order to underline the importance of this technological parameter (relative air humidity *RH*) specimens of the composite material were prepared in the different relative air humidity *RH* levels ($RH_{at T_a} = 20 - 40\%$; $RH_{at 75^\circ\text{C}} = 4 - 6\%$; $RH_{at 40^\circ\text{C}} = 8 - 12\%$; $RH_{Max at T_a} = 65 - 88\%$). The polyurethane binder with different content of the reactive isocyanate -NCO groups (1.8, 2.4% and 7.4%) was used. Different quantity of binder content (8, 13, 18 and 23 wt. %) was introduced based on the considerations of the previous investigations [3, 4]. Shore *C* hardness (Shore scale, according to ISO 7619-1; ISO 868) of the material was determined [7, 8]. The definite number of measurements was carried out in order to insure the certainty of obtained results (for instance, the average value of Shore *C* hardness was calculated from the 27 measurements). Compressive stress of samples at different extent of deformation (30 and 50 %) as well as maximal technically feasible deformation level (67 (Max), %) were investigated according to LVS EN 826 [5].

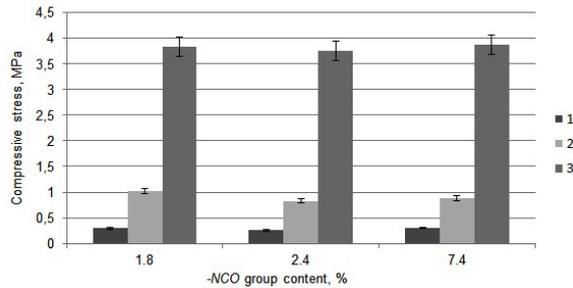


Figure 3. Variation in compressive stress with polymer binder's reactivity at different deformation levels (1 - 30%; 2 - 50%; 3 - 67 (Max) %) of composite material (formation conditions: $T_a = 17 - 20$ °C; $P = 0.004$ MPa, binders content - 18 wt.%).

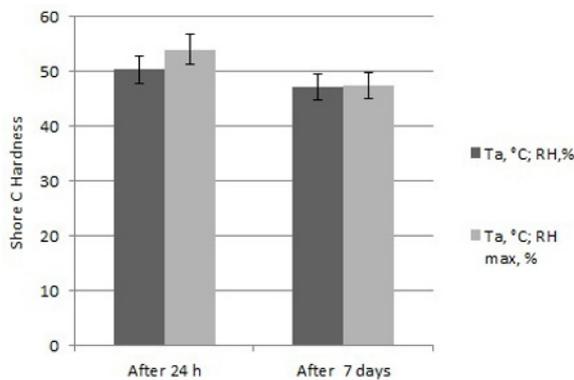


Figure 4. Variation in Shore C hardness of samples prepared at different RH, % measured after several formation times (-NCO 2.4%, binder content 8 wt. %, formation pressure 0.008 MPa).

As a minimum three equal samples of the composite material was produced. Experiment was carried out on the test apparatus *Zwick Roel 7020* at testing rate 50 mm/min. The resistance to UV radiation (LVS EN 14836, *Xenon Test Chamber Xe-1-B*) was investigated for selected composite material samples by examination of the Shore C hardness before and after the radiation on the samples [6]. The specimens were exposed to the ultraviolet UV radiation during 168 h at 70°C temperature without condensation and at definite radiation doze (1.3 W/ m³).

3. Results and discussion

The results of previous investigations showed the correlation between content, technological parameters and selected properties of the composite material. It was shown that the Shore C hardness can be used as an indicator in order to determine the mechanical properties of the com-

posite material [3, 4]. In the present paper the same principle was used and for all specimens the Shore C hardness was determined. The results regarding to the specimens where fractionated scrap rubber crumb was used are shown in the Table 2. It can be seen that Shore C hardness of the composite material is highly dependent of rubber fraction and the amount of binder used in the composite material. The obtained results show that values of the Shore C hardness are strongly connected with the compaction degree of the composite material samples, what conversely, is directly dependent from the fraction size of rubber crumb. Shore C hardness of the composite material was determined after selected formation time (exposition) of the composite material (24 h) and also after 7 days. The ascertained difference (decreasing) in the Shore C hardness after 24 h and 7 days can be explained with the relaxation processes, which took place after removing the formation load of samples (see Table 1). It is connected with superelastic characteristics of the each component of the composite material - rubber crumb and polymer binder [12].

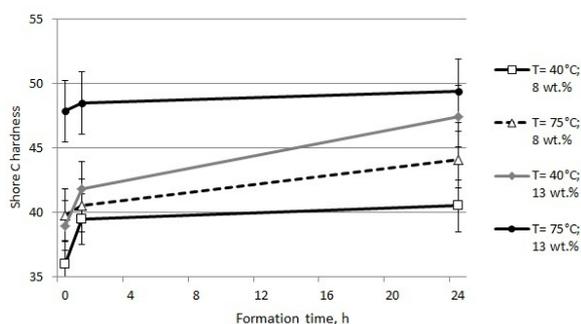
The specimens of the composite material, made at different formation conditions, were subjected to the compressive mode of loading at different deformation levels. The composition of prepared specimens as well as the binder reactivity differs. The obtained results show that in the case when the specimens of the composite material were produced at the temperature T_a (°C) and formation pressure 0.004 MPa, the compressive stress increased with the increase of the binder content in the composite material as well as with the increase of deformation level, as it was predicted (see Figure 2).

The values of compressive stress, in the case when polymer binder's reactivity differs, are showed in the Figure 3. The tendency is quite similar - by the increase of the deformation level values of the compressive stress increases. Small differences in the compressive stress of the composite material with reactivity of polymer binder can be observed, probably, due to the unessential changes in the polymer binder's crosslinking degree, realized in the selected formation conditions of the composite material. In order to examine the effect of the relative air humidity and formation temperature on the composite material properties, additional experiments were carried out. Figure 4 and Figure 5 illustrate the influence of the temperature and relative air humidity on the Shore C hardness of the composite material in close correlation with the polymer binder's content and formation (exposition) time of samples.

If the composite material samples were prepared at T_a temperature and different RH, the Shore C hardness is

Table 2. The influence of formation pressure of composite material specimens (polymer binder with -NCO 2.4 %; formation at $T_a = 17 - 20^\circ\text{C}$) on the compressive stress at different deformation levels.

No	Deformation level, %	Compressive stress, MPa								
		Polymer binder content, 13 wt.%			Polymer binder content, 18 wt.%			Polymer binder content, 23 wt.%		
		Formation pressure P, MPa			Formation pressure P, MPa			Formation pressure P, MPa		
		0.004	0.008	0.02	0.004	0.008	0.02	0.004	0.008	0.02
1.	30	0.147	0.303	0.325	0.254	0.309	0.414	0.318	0.477	0.492
2.	50	0.554	0.984	1.167	0.828	0.979	1.398	1.028	1.611	-
3.	67(Max)	3.850	3.890	-	3.750	3.770	3.870	-	-	-

**Figure 5.** Influence of formation temperature on Shore C hardness of composite material (isocyanate group content 2.4%, formation pressure 0.004 MPa, binder content 8 wt.% and 13 wt.%, formation temperature $T = 40^\circ\text{C}$ ($RH_{at40^\circ\text{C}} = 8-12\%$) and $T = 75^\circ\text{C}$ ($RH_{at75^\circ\text{C}} = 4-6\%$)).

higher when the relative air humidity is $RH_{max.\%}$, which can be explained with the influence of air humidity (presence of water) on the crosslinking of polyurethane-type binder [11]. The influence of formation temperature on the Shore C hardness is demonstrated in Figure 5. It shows, that at higher temperature, higher values of the hardness were observed, if formation time of samples was prolonged till 24 h (the conventional formation time of material samples). It was also found out that those higher formation temperature (75°C) guarantees lower changes of Shore C hardness during all selected formation period till 24 h, independently from the binder content. The results presented in the Figure 5, show impression of formation temperature on the crosslinking processes of the polymer binder (within indicated interval of RH at 40°C and 75°C), which are highly responsible for the final mechanical properties of the composite material.

The effect of formation pressure on the compressive stress of the composite material's samples was examined (see Table 3). The results show, that with the increase of deformation level, content of the polymer binder and formation pressure of the composite material samples, the values of

Table 3. Dependency of Shore C hardness of composite material (formation pressure $P = 0.004$ MPa), containing polymer binder with different reactivity (before and after UV radiation).

Reactive group content -NCO, %	Binder content, wt. %	Formation temperature $^\circ\text{C}$	Shore C hardness before UV radiation	Shore C hardness after UV radiation
2.4	13	T_a	51.7	48.4
	18	T_a	54.8	51.5
	23	T_a	56.0	50.8
7.4	13	T_a	53.6	50.1
	18	T_a	56.2	52.7
	23	T_a	60.6	57.6
2.4	13	40	46.8	47.1
	18	40	48.2	50.3
	23	40	55.6	-

compressive stress of the composite material increases. It can be explained with the increase of the compaction degree of the composite material.

The resistance of ultraviolet (UV) radiation of the composite material was investigated in the correlation with Shore C hardness and reactivity of the polymer binder. The results are shown in the Table 3. The initial hardness of the composite material increases with the increase of the polymer binder amount. However, after UV radiation test Shore C hardness decreases in the case when samples were formed at $T_a = 17 - 20^\circ\text{C}$ and $RH_{atT_a} = 20 - 40\%$. This can be explained with the deterioration of properties of the composite material and a particular degradation of composite material under UV radiation. The samples formed at the higher temperature ($T = 40^\circ\text{C}$; $RH_{at40^\circ\text{C}} = 8-12\%$) after the UV radiation test, shows a little higher UV resistance as it can be seen in the Table 3.

During the experiments it was found out, that the relative air humidity RH (moisture content in the environment) is highly dependent from the temperature. Thereby, also

the moisture content (simultaneously with the temperature) is responsible for the quality of the crosslinking of polyurethane binder [11], which is finally reflected in the Shore *C* hardness of the composite material and also in the resistance of the composite material against *UV* radiation.

4. Conclusions

This particular research of the composite material based on the polyurethane binder with the different reactivity and non-fractionated, as well as fractionated scrap rubber crumb, show, that Shore *C* hardness is dependent from the type of rubber crumb as well as amount of the polymer binder. An estimation of the Shore *C* hardness of the composite material produced both at ambient and at evaluated formation temperatures, and at different relative air humidity, confirmed strong influence of the selected technological parameters on the mechanical properties of the composite material. The results show that with the increase of deformation level and the content of the polymer binder as well as with the increase of formation pressure, the compressive stress of the composite material increases. The results of *UV* radiation tests shows that Shore *C* hardness somewhat decreases due to the deterioration of properties of the composite material and particular degradation of the composite material under *UV* radiation. It was concluded that elevated temperature is the essential technological parameter, in order to improve the resistance of the composite material against the *UV* radiation.

References

- [1] Mark J.E., Erman B., Erich R., The Science and Technology of Rubber, 3rd ed., ed., Elsevier Inc., USA, 2006
- [2] Hughes A.H., Pennington S., Precoated rubber crumb for composites, Pat. GB 2364708
- [3] Malers L., Plesuma R. and Locmele L., Composite Material Based on Recycled Tires, MECHANICS OF COMPOSITE MATERIALS, 2009, T45, No. 1, 1-60
- [4] Malers L., Plesuma R. and Locmele L., The influence of composition and technology on the properties of composite material based on scrap tires and polymer binder, SCIENTIFIC JOURNAL OF RTU MATERIAL SCIENCE AND APPLIED CHEMISTRY, 2011, 23, 103-106.
- [5] LVS EN 826:1996 "Thermal insulating products for building applications - Determination of compression behavior"
- [6] LVS EN 14836:2006 "Synthetic surfaces for outdoor sports areas - Exposure to artificial weathering"
- [7] ISO 7619-1:2010 "Rubber, vulcanized or thermoplastic - Determination of indentation hardness - Part 1: Durometer method (Shore hardness)"
- [8] ISO 868:2003 "Plastics and ebonite - Determination of indentation hardness by means of a durometer (Shore hardness)"
- [9] Shulman V.L., Tyre Recycling, e.d. Smithers Rapra, Shrewsbury, GBR, 2004
- [10] LVS EN 933-1:1995 "Tests for geometrical properties of aggregates - Part 2: Determination of particle size distribution - Test sieves, nominal size of apertures"
- [11] Allen R., Ground rubber elastomeric composite usefull in surfacings and the like, and methods, Pat. US 4112176
- [12] Gent A.N., Relaxation Processes in Vulcanized Rubber. I. Relations between Stress Relaxation, Creep, Recovery, and Hysteresis, RUBBER CHEMISTRY AND TECHNOLOGY, 1963, 36, No. 2, 377-388