Double layer composite material based on elastomer and ultra-high molecular weight polyethylene

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Abstract: Some physical and mechanical properties of a double layer composite material with ultra-high molecular weight polyethylene on one side and elastomer on the other side were evaluated. As elastomer, nitrile butadiene rubber (NBR), isoprene rubber (IR) and styrene butadiene rubber (SBR) were used, and dephynilguanidine (DPG) were used, as adhesive. In this paper we present a progress of our investigations.

1. Introduction
Despite a high variety of the polymer composite materials with unique characteristics, new materials possessing improved operational characteristics are still important [1-3]. One distinctive approach to improve physical and mechanical properties is double layer composite material with a polymer on one side and elastomer on the other side which has been investigated in [4, 5]. In this paper the influence of dephynilguanidine (DPG) to adhesion bond between ultra-high molecular weight polyethylene (UHMWPE) and nitrile butadiene rubber (NBR), isoprene rubber (IR) and styrene butadiene rubber (SBR) as elastomer is investigated.

2. Materials and methods of investigation
Ultra-high molecular weight polyethylene (UHMWPE, GUR-4113) [6], nitrile butadiene rubber (NBR, BNKS-18, Russia), isoprene rubber (IR, SKI-3, Russia), styrene butadiene rubber (SBR, SKS-30, Russia) [7], and dephynilguanidine (DPG, VEKTON) were used. Combination of elastomers with a UHMWPE is possible owing to their close temperature processing windows and a production method – hot pressing technique [8, 9]. Double layer composite material (figure 1) processing is made in 4 stages [10]:

1st stage. Cold molding of UHMWPE in a mould with a pressure 90 kgf/cm\textsuperscript{2} within 5 minutes at room temperature. UHMWPE powder is poured into a mould and there we mold it;

2nd stage. Homogenous laying of the rubber mixture layer upon UHMWPE. Non homogenous laying may cause crack formation of the UHMWPE;

3rd stage. Mould with a UHMWPE and a rubber is placed into hot press for 30 minutes at temperature 155\textdegree C and a pressure 90 kgf/cm\textsuperscript{2}. With a hot molding UHMWPE is pressed into a rubber mixture and with a heat development is passed into a high elastic state, and it enables macromolecule diffusion;
4th stage. Hot pressed sample is cooled to 60°C in a mould under pressure. Shock cooling of a UHMWPE may be a cause of its deformation.

![UHMWPE](image)

**Figure 1.** Double layer composite material based on elastomer and UHMWPE.

Investigations of mechanical and physical properties, include resistance to aggressive environments of the rubber with a different content of a DPG. Stress related characteristics were investigated at rupture machine Shimadzu Autograph according to GOST 270-75. Corrosion resistance IRM-901 in a stress-free state is investigated according to GOST 9.030-74. Investigation of the adhesion bond between elastomers containing different concentration of the DPG and UHMWPE has been made according to GOST 6768-75. Investigation of the structure of interface elastomer boundary layer and UHMWPE has been made at scanning electron microscope JEOL JSM-7800F.

### 3. Results and discussion

Investigation results of elastomer features based on NBR, IR and SBR are presented in the table 1. Concentrations of DPG as – 0.1, 0.2 and 0.3 phr for 100 phr of the rubber.

| N  | Sample       | f, MPa | ε_p, % | f_{100%}, MPa | H, SH A | ρ, g/cm³ | ΔQ, % |
|----|--------------|--------|--------|----------------|---------|----------|-------|
| 1  | NBR          | 10.6   | 410    | 2.4            | 64      | 1.16     | 8.3   |
| 2  | NBR+0.1 phr DPG | 9.3    | 313    | 2.5            | 62      | 1.16     | 8.3   |
| 3  | NBR+0.2 phr DPG | 9.1    | 303    | 2.9            | 63      | 1.15     | 7.9   |
| 4  | NBR+0.3 phr DPG | 8.9    | 285    | 3.0            | 67      | 1.15     | 6.8   |
| 5  | IR           | 7.2    | 707    | 0.7            | 41      | 1.13     | 201.6 |
| 6  | IR+0.1 phr DPG | 14.4   | 724    | 1.3            | 62      | 1.12     | 129.0 |
| 7  | IR+0.2 phr DPG | 14.1   | 689    | 1.3            | 67      | 1.12     | 139.6 |
| 8  | IR+0.3 phr DPG | 14.1   | 666    | 1.3            | 69      | 1.12     | 116.2 |
| 9  | SBR          | 15.9   | 688    | 1.9            | 62      | 1.17     | 41.2  |
| 10 | SBR+0.1 phr DPG | 12.3   | 417    | 2.3            | 66      | 1.16     | 38.5  |
| 11 | SBR+0.2 phr DPG | 11.9   | 414    | 2.4            | 66      | 1.16     | 34.1  |
| 12 | SBR+0.3 phr DPG | 10.9   | 343    | 2.5            | 67      | 1.15     | 35.7  |

f, MPa-tensile stress at rupture; ε_p, %- rupture strain; f_{100%}, MPa –conventional stress at strain 100%; SH A-shore hardness A; ΔQ, %- swelling rating IRM-901.

Table 1 shows that injection of the DPG to the NBR and SBR will lead to the reduction of the extension coefficient and tear resistance as compared to the initial sample. Nevertheless, we may see slight module elevation at 100% tensile strain. Injection of the DPG has rather different impact on the
mechanical and physical properties of the IR: its rupture strain is changing slightly, nevertheless its tear resistance is doubled at 100% tensile strain.

Injection of the DPG has a different affect on the rubbers according to the Shore hardness. Quintessential effect of the injection has on IR where Shore hardness rises up to 1.6 times. Shore hardness A of the NBR and SBR is slightly changing with injection of the DPG. There has been observed a rise of a Shore hardness A of a SBR by 4-6 durometers. Rubbers density is not changed by the injection of the DPG. Corrosion resistance of all samples IRM-901 rises up. Most significant rise has been observed (up to 1.7 times) with IR.

![Graph](image-url)

**Figure 2.** Double layer composite material adhesion dependence and failure resistance of elastomers on dephynilguanidine.

Figure 2 shows dependence diagrams of elastomers, failure resistance, and adhesion force between the rubbers and UHMWPE depending on DPG content. With increase of DPG concentration in the rubber mixture, supposedly owing to formation of sulphide entities between macromolecules of elastomer and UHMWPE, adhesion build appears.

It is clear that injection of DPG into rubber mixture, and also its increasing concentration will lead to adhesion. However, it should be noted that adhesion measurement at the rupture machine shows that in some cases there is a layer separation across phase boundary between the rubber and UHMWPE, and in some cases across the rubber. Rubber layer separation indicates excess of adhesion force between the rubber and UHMWPE over cohesion strength inside the rubber. In such cases, observed adhesion force in N, is an indication of rubber strength properties but not of adhesion.

For the NBR separation of specimens containing 0.1 and 0.2 phr of DPG as UHMWPE is passing in integrated way, i.e. wearing takes part partially by rubber and partially by interfacial interaction rubber/UHMWPE. Wearing has a cohesion character if there is a separation of specimens containing 0.3 phr.

If there is a rise of concentration of DPG in IR one may observe as hardening at elastomer rupture, as adhesion bond with UHMWPE. Hardening at materials structure violation was equal 370% regarding the rubber without DPG. Still, rubber separation with 0.3 phr of DPG is going on across elastomer.

After injection of 0.1 phr of DPG into SBR, separation is taking part partially on boundary and partially on rubber. After injection of 0.2 and 0.3 phr of DPG into the rubber mixture, separation is taking part across elastomer.
Rise of adhesion bond between the rubbers containing DPG mixed with UHMWPE is probably explained by the fact that DPG is a vulcanization accelerator where sulphide generation process between macromolecules is accelerated [8, 11]. It is determined in papers [12-14] that injection of DPG into polyethylene sulfonation will lead to formation of sulphides between polyethylene macromolecules that may point at formation of sulphides between the rubber and polyethylene. Usage of DPG as an elastomer adhesion bond catalyst with UHMWPE leads to the formation of sulphides between them, it is shown at figure 3.

![Figure 3](image_url)  
*Figure 3. Formation of sulphides between elastomer and UHMWPE.*

Research of supramolecular structure of the double layer composite materials of the interphase boundary revealed that injection of the DPG into the rubber mixture leads to the significant changes by way of formation vesicular structure of the UHMWPE. Figure 4 (a, c, e) shows micrographs of UHMWPE boundary with the rubber without adding DPG. Figure 4 (b, d, f) corresponds to injection of 0.3 phr of DPG into the rubber mixture. Observed structural changes may indicate formation of sulphides between UHMWPE and elastomers, which lead to rise of adhesion bond.

### 4. Conclusions

It is shown that hardening of adhesion bond between elastomers and UHMWPE mainly depends on vulcanizing system. Injection of the DPG into the rubber mixture leads to an increase of the adhesion bond between the elastomer and UHMWPE and influences vesicular structure near interface boundaries.
Figure 4. Micrographs of UHMWPE transitional layer with elastomers a) NBR b) NBR + 0.3 phr DPG c) IR d) IR + 0.3 phr DPG e) SBR f) SBR + 0.3 phr DPG.

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