Effect of Accelerated Ageing Conditions on the Protective Properties of Anti-Blow Products

Abstract

This article presents research on protective packets of anti-blow vests in use among law enforcement services of the Polish Police. Basic information on the ageing process of polymer plastics are given. The types of ageing are presented as well as the phenomena causing the process within the plastics. The approved programme of accelerated ageing tests of the protective packets of anti-blow vests was characterised. The conditions of the tests were defined as well as the groups of properties to be tested, which are the criteria of the resistance of the test objects to ageing. The results of the research on the protective properties of anti-blow packets before and after tests of laboratory ageing are presented. The results of the research on packets of anti-blow vests after 10 years of real-time ageing are also presented. A concluding analysis of the research results and impact of ageing processes on the protective properties of the products tested was performed.

Key words: ageing, accelerated ageing, anti-blow products, protective properties.

Introduction

The law enforcement services of the Polish Police use some anti-blow protective products in operations, including helmets, vests, limb protectors, as well as products featuring a multi-layer and multi-material structure.

Virtually, every element of anti-blow protection is made of plastics like polyethylene, polypropylene, polyvinyl chloride, polycarbonate, polyesters, polyamide, etc. Plastics are subject to ageing i.e. they change their properties as time passes by. This is caused by the impact of many factors - physical, chemical or biological, among which the following may be mentioned: visible light within all the range of the spectrum, ionising radiation, oxygen, heat, humidity and active chemical compounds – both organic and inorganic [1].

Due to the origin of the process, two types of ageing might be distinguished: real-time and simulated at accelerated conditions. Ageing is also classified depending on the source of the phenomena that cause the process and on the kind of environment in which it occurs. In the case of materials exploited outdoors, the impact of climatic agents (sunlight, heat, rain and wind) causes the progressive deterioration of a material’s properties. Such a process is called atmospheric ageing, which occurs according to two basic mechanisms: photo-oxidation and thermal oxidation. Photo-oxidation is a result of radiation, mainly of the UV band, whereas thermal oxidation happens on exposure to oxygen at raised temperatures [2].

The rate of ageing mainly depends on the kind of plastic and conditions of usage. Ageing may be of a chemical or physical nature. Every plastic is subject to chemical ageing, which means alterations in the chemical structure of the polymer on exposure to light, UV radiation, oxygen from the atmosphere, temperature or humidity [3 - 7]. Chemical ageing is characterised mainly by a loss of good mechanical properties. Other symptoms are tarnishes, crazings and bronzes. Chemical ageing causes plastic degradation, consisting of a line of chemical processes linked to the creation of oxides and peroxides, cracking macromolecular chains, cross-linking, and the creation of chemical double bonds (reason for bronzes). Manufacturers of plastics prevent early chemical ageing by adding a packet of stabilisers, anti-oxidants and UV-stabilisers, volumes and combinations of which depend on the kind of plastic and its use.

Physical ageing is a process which only plastics exploited below their glassy temperature are subject to. The nature of physical ageing is a change in the compaction of macromolecules at the amorphous phase, which leads to brittleness and the easy cracking of the material [8 - 12]. The process of physical ageing is inherently reversible: heating the material above the glassy temperature and cooled back, may restore its good properties. Unfortunately, you cannot do this with ready-made goods since they lose their shape upon heating. Partially-crystalline plastics display other kinds of changes, time-related and temperature-related, which consist in re-crystallising or improving the crystallisation of the material. Re-crystallisation also usually causes some deterioration of mechanical properties and loss of the material’s ability to become deformed in a malleable way.

The assessment of materials’ resistance, including plastic products, to environmental conditions requires prior execution of research on ageing under real conditions anticipated during exploitation i.e. so-called proving ground tests, consisting in locating samples of a given material or ready-made product outdoors and exposing them to ageing for a period no shorter than a year. The minimum time of real-time ageing assumed for the research of plastic is 5 years. The time-consumption of such research has forced the development of accelerated ageing methods which simulate natural conditions inside of laboratory apparatus, thus
allowing the intensifying action of agents to impact the polymer and accelerate the process of ageing [1].

Object of research

The objects of the present accelerated ageing research were protective packets of anti-blow vests (protection of the Patent Office of the Republic of Poland – P 327897):

- new and
- after 10 years of usage under Central European climate conditions.

The design i.e. the arrangement and thickness of layers and material composition as well as the materials and their properties of all the packets tested were the same.

Programme of research on ageing

Determining the conditions of ageing tests

The protective properties of an anti-blow packet are mainly determined by three, chemically different materials i.e. foamed polyethylene with closed cells (PE foam), panels of polyvinyl chloride (PVC), and foamed polyurethane plastic of tubular structure (PU foam).

Presumably the subject of analysis of the ageing tests is the change in the protective properties of the packet, considered as a whole, but not variations in its components. The impact of ageing conditions on the individual materials of the packet is caused by multiplanar phenomena, specifically their multiplicity and variety, thus requiring separate study.


The ageing of the anti-blow packets was conducted in two ways:

- under hot and dry conditions in a thermal chamber from BINDER GmbH
- under hot and humid conditions in the thermal chamber

Parameters of the ageing process:

- temperature – 70.0 ± 0.5 °C, which is the temperature recommended by Standard PN-EN ISO 2440: 2001 for olefin polymers. Since the main compound of the packets was PE foam, a temperature of 70.0 ± 0.5 °C was assumed as the ageing temperature of the whole packet,
- ageing time – 168 days subdivided into the stages:
  - stage I – 8 cycles, 7 days each (total 56 days),
  - stage II (continued ageing) - 8 cycles, 14 days each (total 112 days),
- number of samples – 8 packets of A4 size for each ageing cycle,

- under hot and humid conditions in the thermal chamber
- number of samples 1 packet of A4 size for each ageing cycle.

Methods and criteria for the assessment of the test products’ resistance to ageing

The anti-blow packets aged under laboratory conditions were tested at the end of every ageing cycle for changes in the following properties:

- resistance to impact – according to procedure PBB-07 “Impacting tests. Estimating the level of energy attenuation by body protectors” of the „MOR-
ATEX Institute, developed on the basis of Standard BS 7971-8: 2003 [15]. Tests were executed using a drop tower testing machine manufactured according to the requirements of Standard BS 7971-4: 2002 [16]. The main components of the workstation are an anvil with a sensor for measuring the magnitude of the impact force transferred, and a hammer for impacting the surface subjected to testing. Testing consisted in placing an A4-size packet sample on a cylindrical anvil of 150 mm radius and hitting it with a flat impacter with an energy of 20 J at 3 different points on the packet, determined with respect to the boundary conditions. The magnitude of the force transferred beyond the sample was registered, which typifies the resistance of the product to blow and should not exceed the critical value (4 kN).


A tension tester from ZWICK was used for the testing, which allowed to compress the test samples of the packet of 10 × 10 cm size between the base plate the sample was placed on and the pressing plate. The sample was subjected to pressing at a constant velocity of 100 ± 20 mm/min. Each test was executed on 3 samples. The force in N which caused 40% compression was registered, and the value of the pressing tension in kPa was calculated according to the formula stated in the Standard.

### Results and discussion

On the basis of the test results obtained from anti-blow packets both before and after each ageing process cycle, graphs of the impact of the ageing time were drawn with respect to the following:

- the force in kN transferred beyond the sample tested, according to PBB-07.

The force reflects the resistance of the packet to blow. Figure 3 shows a graph of the dependence under hot and dry conditions, while Figure 4 depicts that under hot and humid ones. The results of the tests, shown in Figures 3 and 4, were approximated with the exponential function:

\[ y = y_0 + A_1 e^{x/t_1} \]

where: \( y_0 \), \( A_1 \) and \( t_1 \) are coefficients calculated for the function chosen on the basis of experimental data.

- the stress tensile required to compress the packet down to 40% of its original thickness – CV40 in kPa under hot and dry conditions (Figure 5 see page 64) and humid and hot ones (Figure 6 see page 64).

It should be emphasised again that because of the assumption made before (see page 62 - Determining the conditions of ageing tests), they are the results of tests of a whole packet. The analysis of the impact of the ageing of each of the materials applied in the packet on the behaviour of the whole packet, regarding their diversity, both the chemical and physical properties is the subject of separate research presently carried out by us.

**Table 2.** Results of tests on packets after a 10-year period of usage.

<table>
<thead>
<tr>
<th>Item</th>
<th>Parameter</th>
<th>Results of tests of vest no.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pressing tension at 40% compression CV40, kPa:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>measurement 1</td>
<td>48.2</td>
<td>46.5</td>
<td>40.8</td>
<td>41.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>measurement 2</td>
<td>40.7</td>
<td>41.3</td>
<td>37.7</td>
<td>37.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>measurement 3</td>
<td>39.9</td>
<td>39.6</td>
<td>35.9</td>
<td>35.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>measurement 4</td>
<td>39.7</td>
<td>39.4</td>
<td>36.6</td>
<td>35.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mean value</td>
<td>42.0 ± 4.2</td>
<td>41.7 ± 3.3</td>
<td>38.0 ± 1.9</td>
<td>37.3 ± 2.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Resistance to blow (maximum force transferred beyond test sample), kN</td>
<td>3.4 ± 0.1</td>
<td>3.7 ± 0.1</td>
<td>4.8 ± 0.5</td>
<td>4.0 ± 0.2</td>
<td></td>
</tr>
</tbody>
</table>

![Figure 3.](image1.png) **Dependence of aged packets’ resistance to blow on the ageing time under hot and dry conditions (temp. 70.0 ± 0.5 °C).**

![Figure 4.](image2.png) **Dependence of aged packets’ resistance to blow on the ageing time under wet (50.0 ± 1.5% humidity) and hot (70.0 ± 0.4 °C) conditions.**
significant changes in the parameter were observed (maximum ca. 21%), whereas at high temperature (70.0 ± 0.4 °C) and under humid conditions, the critical time, after which the magnitude is passed, is more than 4-times shorter than under hot and dry conditions.

The results of the tests of the packets of used vests (Table 2) show that after 10 years of real-time ageing, the resistance to blow of most of those products reaches the critical magnitude i.e. 4 kN.

The pressing tension at a compression of 40% also shows remarkably faster changes under hot and wet conditions (Figure 6) than under hot and dry ones (Figure 5). The former case shows a remarkable increase in the parameter as the results of tests on a vest after 10-years of exploitation prove.

4. The arrangement of the 3 materials selected, applied in the protective packet of anti-blow vests, provides a high level of protection throughout a long period of usage.

5. The research described in the article confirms the correctness of the method chosen for the laboratory simulation of the ageing of anti-blow packet.

The effect observed is new, and its explanation requires further research e.g. at the level of each component of the packet.

Conclusions

1. The present research proves the significant impact of ageing conditions (temperature, humidity) on the rate of proceeding the ageing processes.

2. The conditions of the Central European climate, where anti-blow vests are actually used, feature a humidity within a range of 40 - 60%, whereas, considering the temperature, are softer than those assumed for the programme of accelerated ageing research.

3. Degradation processes occur much more slowly in natural conditions of use than in laboratory conditions, as the results of tests on a vest after 10-years of exploitation prove.

4. The arrangement of the 3 materials selected, applied in the protective packet of anti-blow vests, provides a high level of protection throughout a long period of usage.

5. The research described in the article confirms the correctness of the method chosen for the laboratory simulation of the ageing of anti-blow packet.

References


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