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Measurement of Joint Durability between an Aluminum Foil and Basalt Fabrics

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Abstract
The aim of this paper was to determine the adhesion force between an aluminum foil and basalt fabrics. Aluminised basalt fabric can be used as an alternative solution for protective clothing production. So far aluminised glass fabric has been used for this purpose. The lamination of basalt fabrics with aluminum foil does not changed fabric flexibility and can provide better protection against thermal radiation. To check different variants of adhesion, fabrics reinforced by a steel wire were also used (wire diameter 0.1 mm). The steel wire caused an increase in the fabric tear strength as well as in puncture and cut resistance. Two types of glue were chosen to carry out an investigation on the strength of adhesive bonding (Butacoll A+ and Bonatex PU85). The adhesion strength of the laminates was measured according to the PN-88/P-04950 standard. The test results confirmed higher values for weft directions and the phenomenon of asymmetry of the bond strength was found during testing.

Key words: *joint durability, aluminised basalt fabrics, lamination, glass fibres.*

Introduction

Basalt fibres belong to the heat radiation resistant fibre group – a subgroup of fibres characterised by ultra-high temperature resistance. Basalt fibres and products made from them have a low moisture absorption, low thermal conductivity, good thermal stability and low values of extension at break. The properties of basalt fibres may constitute a great alternative to the glass fibres currently used in protective clothing production [1-4]. Basalt fibres have unique physicochemical properties, unattainable for traditional glass fibres.

A comparative analysis of basalt fibres with the glass fibres of the E type traditionally used showed that basalt fibres are characterised by higher values of tensile strength, Young's modulus and by a wider range of working temperatures. Glass fibres are also characterised by good mechanical strength, light weight and good surface finishing [5-7]. Not only glass fabrics are used for the production of protective clothing. Very common in such a product are aramid fabrics covered with aluminum foil or without it, and also combined with cotton and wool fabrics with flame-retardant finishing [8-10]. Although information about the different aspects of basalt fibre application in world literature is widely described, there is a need for investigations of fabrics made of basalt fibres from the point of view of different application conditions. Moreover, a lack of the negative influence of such fabrics on the human body has also been reported. Because of the natural origin of basalt fibres, they are nontoxic and do not pollute the environment [11-13].

Nevertheless, using products made of basalt fibres may cause a mechanical irritation of the skin, upper respiratory tract and eyes. The same situation occurs while using protective clothing made from glass fabrics. Fortunately, the mechanical irritations are not long-term changes, and are treated only as allergic reactions. Short mechanical irritations can be eliminated by using aluminised fabrics. To eliminate possible allergic reactions upon the contact of either glass or basalt fabrics with the human skin, the step of fabric lamination was introduced. The combination of layers of basalt fabric with aluminum foil is possible by matching commonly used resins (e.g., epoxy, polyester, acrylic, polyurethane) [1, 14, 15]. The more important explanation why fabrics are covered by aluminum foil is the desire to increase radiant heat resistance. Aluminised fabrics reflect 80~90% of radiant heat [23]. Investigation on two types of lamination were carried out by Jin et al. [16], who found that fabrics covered by double-sided aluminised film achieved a higher range of heat reflectance than those with a single-sided cover. Cai et al. [17] carried out measurements on the thermal insulation properties of aluminised aramid fabrics. Covered by aluminum, the aramid fabrics reflected the infrared wavelength in the range of above 85%. They concluded that the smooth surface of fabrics had a better reflectance performance. Ghane and Sarlak [18] studied the radiant heat flux transfer through aluminised multi-layer protective clothing made from glass fabrics. They established that the aluminized clothing caused an increase in the thermal protective performance of clothing.

Basalt fabric can be an alternative solution for protective clothing production and can replace fabric made from glass fibres due to the similar properties and lower price. A comparison of the properties of basalt and glass fabrics was made by authors Hao and You [19], who found out that basalt fabrics have better stability after thermal treatment than glass fabrics. Due to the very good heat radiation resistance of basalt fabrics after coating, they can also be used as protection against fire [20, 24]. Frydrych et al. [21] in their work used aluminised basalt fabric for creating a new kind of protective clothing. They made a thermal insulation comparison between two different kinds of protective clothing: a traditional one made of aluminised glass fabrics and a new one made of aluminised basalt fabrics. For this purpose thermal factors like resistance to big molten splashes, resistance to contact and convective heat as well as radiant heat resistance were measured. Test results showed that aluminised basalt fabrics have the same level of protection as aluminised glass fab-

Table 1. Characteristics of aluminised basalt fabrics and type of glue. ***Note:*** *L – laminate, i.e., basalt fabrics covered by aluminum foil.*

Symbol of sample	Weave	Mass per square meter, g/m^2	Thickness, mm	Type of glue
L1	plain	329	0.31	Butacoll A+
L2	plain	508	0.43	Butacoll A+
L3	twill	443	0.55	Bonatex PU85
L4	plain	505	0.67	Bonatex PU85
L5	twill	512	0.62	Butacoll A+
L6	plain reinforced with a wire	380	0.48	Butacoll A+
L7	twill reinforced with a wire	388	0.65	Bonatex PU85

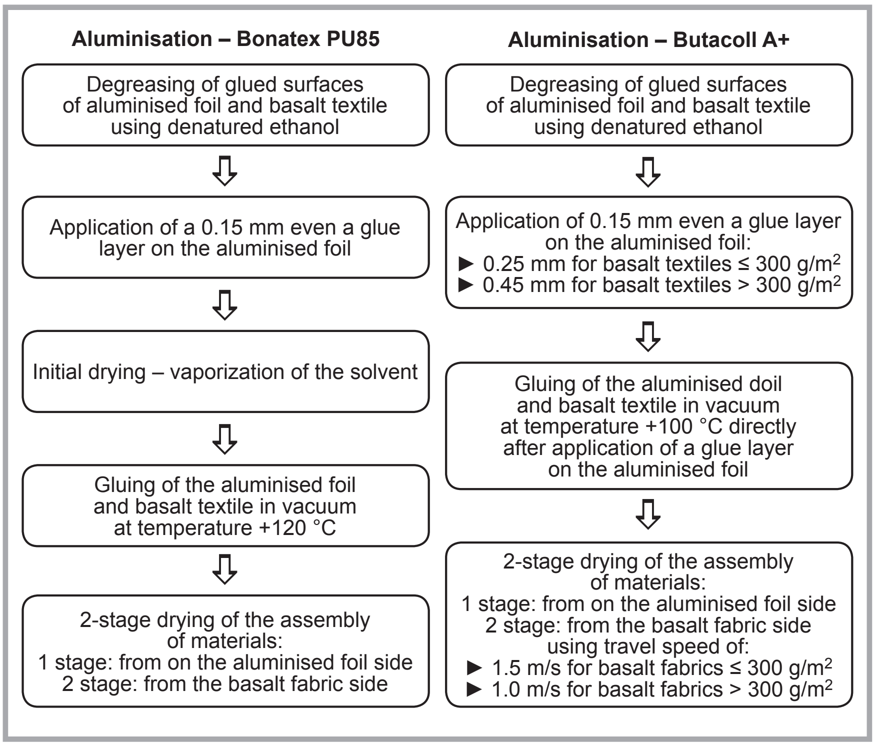

Figure 1. *Flowchart describing steps while joining the aluminum foil with basalt fabrics [12].*

rics in terms of resistance to big molten splashes, contact and convective heat. Aluminised basalt fabrics achieved much higher resistance to radiant heat than aluminised glass fabrics.

Due to the high mechanical resistance, basalt fabrics can be used for protective means such as in protective gloves for specific job activities which can cause glove damage during work. In their work Hrynyk et al. [12, 22] focused on a new glove construction as well as on the usage of aluminised basalt fabrics to create protective gloves. It was necessary to carry out the mechanical examination of those products in terms of cut resistance, abrasion, tear resistance and puncture resistance measurement. After all those tests they found that the fabrics chosen complied with the current standard: EN 388:2003.

A feature of aluminised basalt fabric is the existence of adhesion between the joined layers of materials (basalt fabric and aluminum foil). The irregular structure of the textile surface enables bonding with the aluminum foil due to the fact that the adhesive medium penetrates the pores and facilitates the lamination process, which is why the aluminum foil covers the fabric in a specific way. It is also important to note that not all kinds of aluminum foils are adequate for covering fabric destined for protective clothing. Aluminum foils used in the industry can be rapidly destroyed, but they have a good resistance to radiant heat. Much higher resistance to mechanical damage, such as cracking, crumbling and delamination, can be attained by sputtering a layer of aluminum on polymer films combined with materials used for the manufacturing of personal protective equipment, especially gloves and protective clothing. For this purpose polymer films coated on one side by a layer of aluminum have usually been used.

Due to the natural small stresses occurring during the use of protective clothing, such as bending, which causes cracks and reduces the effectiveness of protection against thermal radiation, in this case polymer films were coated by aluminum foil on both sides. An action like this does not significantly affect the thickness and flexibility of the fabric. This solution is a compromise between ensuring adequate handle of the material and protective properties. The aluminum foil is joined to the fabric in this way with a specific glue.

An inadequate process of joining the aluminum foil with the fabric can result in the formation of blistering, the delamination of layers, and heterogeneity in the structure of the multilayer material. Delamination can also be caused by different glue penetration inside the material, which, at the same time, creates different adhesion forces in various places. Destruction of the laminate occurs especially when the laminate is subjected to frequent deforming forces and changes of temperature.

The aim of this paper was to check the durability of bonding aluminum foil with basalt fabrics using two different types of glue.

Materials and methods

In order to examine the adhesive forces between basalt fabric and aluminum foil, seven different fabrics were tested, varying in terms of weave, type of adhesive medium, and way of bonding. All basalt fabrics used in the study were manufactured using a shuttleless rapier loom [12]. Depending on the degree of glue penetration in the material, the resulting combination of components may be characterised by different stabilities. Additionally, in the case of two fabrics, the weave was reinforced by a steel wire (wire diameter 0.1 mm) – fabrics L6 and L7. The steel wire caused an increase in the fabric tear strength as well as the puncture and cut resistance. Characteristics of the aluminised basalt fabrics and type of glue are given in ***Table 1***.

Process of joining aluminum foil with basalt fabrics

Materials used for the research are intended to create protective clothing, and therefore protective properties should remain at a high level. The durability of bonding the aluminum foil with basalt fabrics is a crucial parameter that provides protection against thermal and mechanical factors. Not suitably matched parameters of the gluing process may cause a delamination of layers, producing a heterogeneous structure and, consequently, a lack of expected protection against thermal and mechanical factors. Selection of the right glue and bonding method that provides relevant properties of the materials tested were necessary. Glue Butacoll A+, made from a multi-component epoxy resin (acetone, toluene, 4-tetra-butylphenol), is insoluble in water [23]. Glue Bonatex PU 85 is an adhesive dispersion based on aqueous dispersions of synthetic resins and polyurethanes. The method of bonding the foil on the basalt fabric side does not influence fabric flexibility and precise sensory comfort. The first step in the process of combining aluminum foil with basalt fabrics was degreasing the fabric surface. Then the exact amount of glue was put on aluminum foil of 12 µm thickness. The application of a glue layer was as follows: 0.45 mm – for Butacoll A+ & 0.15 mm – for Bonatex PU 85. Combining of the layers was carried out under the pressure at a temperature of +100 °C – for glue Butacoll A+, and +120 °C – for Bonatex PU 85. Next, two-stage drying of the material followed, first on the foil side and then on the basalt fabric side [12]. Flowcharts of the processes described are presented in ***Figure 1***.

Measurement of adhesion forces between the basalt fabric and aluminised foil

The adhesion force of the laminates was measured according to Polish Standard PN-88/P-04950. The research was conducted in normal climatic conditions, i.e., at a temperature of 20 °C ± 2 °C and relative humidity of 65% ± 2%. Research was carried on a tensile machine – Hounsfield H10K-S (Tinius Olsen) equipped with an original program for the registration and statistical analysis of data obtained in the measurements and with a special measurement head with a strength range of 100 N. The machine is equipped with two pneumatically lockable clamps for mounting the sample (***Figure 2***): bottom – stationary and an upper, which after the start of the measurement moves up at a constant speed of v = 100 mm/min; the distance between clamps was 200 mm. The measurement ends when the distance of delamination (120 mm) is complete. Then the clamp automatically returns to its initial position. The delamination force (adhesion force) in the weft and warp directions is recorded, and the values of the variation coefficient of the delamination force are calculated. It was necessary to perform tests for 5 samples for both directions (warp and weft) [25].

Results

The results of adhesive forces are presented in ***Figure 6***. As a result of the studies performed, it was found that there was the phenomenon of the asymmetry of the adhesive force (different values in the weft and warp directions – a higher value for the weft direction). This occurs for almost each variant of basalt fabrics (exception – L1 & L5 fabrics). Due to the different floating points of the fabrics and adhesion of the interface fabric – aluminum foil, which are shaped by many factors such as the type of fabric weave, deformation of the bonded surfaces occurs, caused by clamps and so on. Fabric L1 has the lowest adhesion force among all the ones examined and the lowest standard deviation of these values, which is due to both the uniformity of the individual sample as well as very small differences in the adhesion force between the bonded layers, owing to irregular glue placement.

During the examination, in a few cases of the fabrics tested, it was easy to see irregular glue penetration even before starting the tests. This can be caused by the loose structure of basalt fabrics, which can cause that the glue is visible on the right side of the fabric (***Figure 3***). Moreover, in some cases the adhesion between the fabric and aluminum foil was so strong that it caused damage to the basalt fabric as well as to the aluminum foil during tests (***Figure 4***).

Additionally, there was a problem with the delamination of fabric L7 in the weft direction. Moreover, there were no possibilities to achieve test results for fabric L7 in the weft direction. Adhesion between the aluminum foil and fabric was too strong, thus we could not measure it by means of this load cell. During the examination, the aluminum foil was torn, which did not allow to achieve the appropriate force result (***Figure 6* – ***).

Figure 2. *Position of sample during the test.*

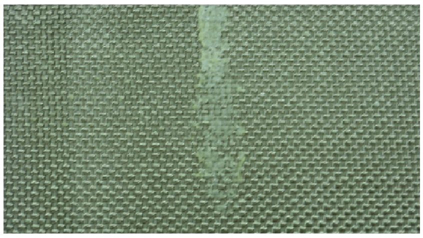

Figure 3. *Glue layer visible on the right side of fabric – L4*

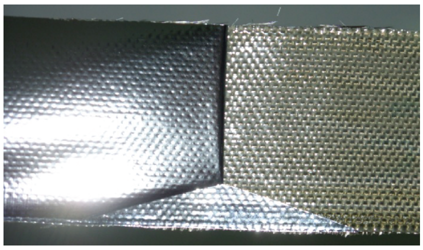

Figure 4. *Damage occurring during examinations – L7.*

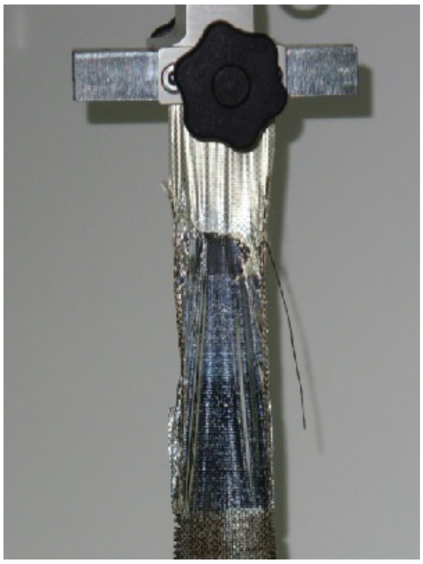

Figure 5. *Strong adhesion between the aluminum foil and basalt fabric – L4.*

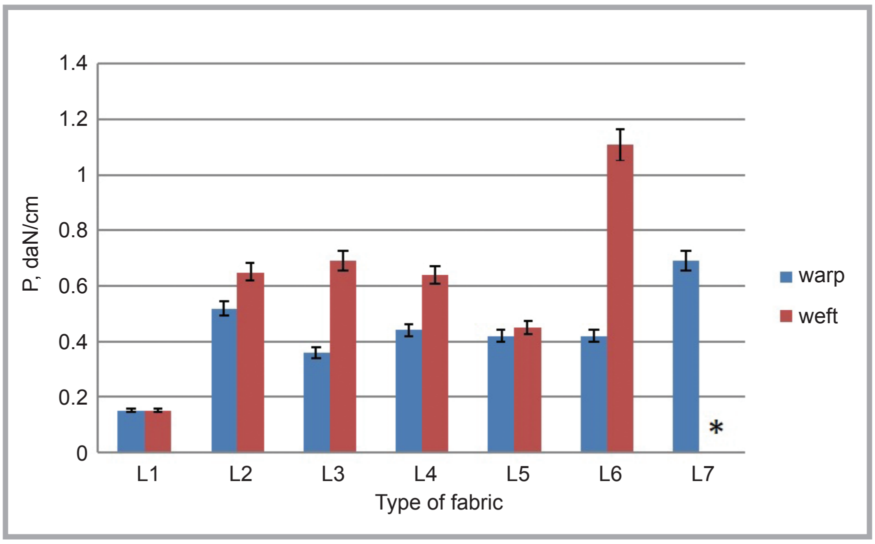

Figure 6. *Average values of adhesion forces.* ***Note:*** ** – lack of test results for fabric L7.*

Conclusions

Bigger values of adhesion forces were achieved for fabrics L6 and L7 (containing the wire) bonded with Bonatex PU85 glue. The problem of basalt fabrics reinforced by the wire joined with aluminum foil by Bonatex PU85 glue was that the process of delamination was not easy to control during measurements, as shown earlier in ***Figures 4*** and ***5***. Delamination for samples with Butacoll A+ glue ran more regularly and gave small differences for both thread directions (exception – fabric L6 with a wire). Fabric L5 seemed to be the most stable during examinations. Moreover, the fabrics combined with Butacoll A+ glue fulfill the requirements necessary for protective clothing, confirming better test results for these variants in this work. During measurements, uneven values of force were recorded, which may be caused by a different glue penetration. Moreover, samples taken from the same type of fabric showed big differences in values of delamination forces, due to the irregularity of glue placement.

Results of the mechanical properties allowed to evaluate the durability of two different glue joints (bonds) between the aluminum foil and basalt fabrics. Additionally, asymmetry of the glue bounding resistance was noted. The different results of the adhesion force obtained for the particular samples are caused by the different thread and glue arrangement in them.

Research on improving the quality of the joints described will be continued.

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