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Thermal Manikin Measurements of Protective Clothing Assemblies

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Abstract
The thermal comfort of a foundry worker is very important and related to many factors, i.e., the structure of the protective clothing assembly, the number of layers and their thickness, as well as the distance between the body and appropriate underwear. The research undertaken aimed at checking thermal insulation for assemblies consisting of aluminized protective clothing and appropriate underwear in two sizes and without underwear. Measurements of the clothing thermal insulation were conducted using a thermal manikin dressed in two-layer protective clothing and three kinds of underwear products covering the upper and lower parts of the manikin. The first part of the paper presents a comparison of results of thermal insulation measurement of two kinds of protective clothing: a traditional one made of aluminised glass fabrics and a new one made of aluminised basalt fabrics. Each of the protective clothing was worn on three kinds of underwear products in m and s sizes. The influence of the underwear size was noted. In the second part of paper, measurements were made for two aluminized basalt clothing variants: commercial and a prototype with modifications in static and dynamic conditions. The results were discussed.

Key words: *foundry worker, protective clothing, aluminized basalt fabric, aluminized glass fabric, thermal insulation, clothing, underwear.*

Introduction

The main aim of the research undertaken was to produce a protective clothing model for a foundry worker with the use of assemblies containing aluminised basalt fabrics. So far such a kind of clothing has been produced from aluminised glass fabrics. Many researchers have indicated that basalt fibres, characterised by bigger values of tensile strength and thermal resistance, have a wider range of working temperatures in comparison to the traditionally used E glass fibres, and for this reason they can replace glass fibres. The results of initial research on the properties of basalt fabrics and their application were published in [1 - 3]. Research carried out previously aimed at modelling selected protective and biophysical properties of clothing assemblies based on aluminised basalt fabrics.

In the case of protective clothing, it is very important to ensure appropriate protection against dangerous situations, utility in such a way that the job's activity does not cause any accidents, and at the same time utility comfort. A very important aspect from the employer's point of view is the product price. Optimisation of the foundry worker clothing material assembly should take into account new materials produced by new technologies which are characterised by high strength and barrier properties, a relatively low clothing weight and good utility properties at an acceptable level of cost [4].

Analysis of the protective properties of textile assemblies based on aluminised basalt fabric showed the same protection efficiency level as those based on aluminised glass fabric [5]. On the basis of results of research performed so far [26, 27], it can be stated that the textile assembly consisted of aluminized basalt fabric (of twill weave and mass per square meter equal to 450 g/m^2) and the wool fabric finished non-flammably, was the best for application in protective clothing for a foundry worker. This assembly was used for sewing the protective clothing assigned for a foundry worker.

The thermal comfort of a foundry worker is related to the following factors: the structure of the protective clothing assembly, the number of layers and their thickness, the distance between the body and appropriate underwear, and so called air gaps. The air gaps are related to the clothing size. Our research aimed first at checking the thermal insulation values of protective clothing sewn from the new material assembly, i.e., aluminized basalt fabric + wool lining finished non-flammably, and next at the investigation of the influence of the size of clothing and underwear on the clothing set's thermal insulation. A comparative analysis is based on the thermal insulation measurements of different kinds of protective clothing: first a traditional one based on aluminized glass fabric and a new one based on aluminized basalt fabric; second, different models of aluminized basalt clothing Measurements of clothing thermal insulation were conducted using a thermal manikin dressed in the protective clothing and three kinds of underwear products covering upper and lower parts of the manikin or only in the protective clothing. These underwear products were in two sizes S and M (manikin is of size M) to check the influence of the distance between the body and underwear on the thermal comfort of the user. Additionally the influence of the manikin's movement on the thermal insulation was examined by means of measurements in the static and dynamic conditions.

State of the art – thermal manikin application

Thermal manikins are tools that assess clothing thermal insulation [6 - 9], and are very often used nowadays. Such a measurement method allows to obtain precise and repeatable results of protective clothing insulation. Thermal manikins available on the market are characterised by different technical parameters, construction materials, shapes and the number of segments. Irrespective of their construction, thermal manikins should provide reliable and comparable values of measured parameters [7, 11].

In recent years, very complex manikins consisting of 123 segments with the possibility of sweating [10] have appeared on the market. Such manikins are used for measurements in closed rooms and vehicles. Enterprises producing sport and protective clothing use simpler models of thermal manikins [6] for the determination of thermal insulation of selected clothing, equipped only in the heating function.

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The level of correlation between the results of thermal insulation obtained from thermal manikins of different construction produced by different companies should be high. In 2001 research was performed on result correlation in three laboratories where protective clothing was measured. Unfortunately a big variability of results was noted. The reasons for this were differences in the construction of manikins, different methods of result calculation and not enough precise control of measurement conditions [12 - 13]. Two laboratories used the manikin NEWTON, which consists of 26 and 34 segments, successively, whereas the third laboratory had the manikin TORE, consisting of 17 segments. Taking into account the differences in the manikin construction, calculations of the thermal insulation for each clothing type were done for each group of segments separately – only for the upper segments of the manikin's body (torso and shoulders), and for the upper and lower manikin segments together (adding hips and legs). Results showed differences of about 13 - 14% and those for clothing of lower air permeability at the level of 6 - 15%, whereas results for the clothing of higher air permeability had differences of about 25 - 29%.

Measurements performed in clothing enterprises on thermal manikins gave repeatability at a level of the variation coefficient equal to 5%. Measurements [14] carried out on volunteers and thermal manikin proved that the difference in the clothing thermal insulation in a climatic chamber without wind was 13%. Higher values of thermal insulation were obtained in the case of measurement on volunteers than on the thermal manikin. Nevertheless measurements carried out on the thermal manikin were a few times more precise than those performed on volunteers (measurement uncertainty for the thermal manikin was 2%, whereas in the case of measurements on volunteers it was 12 - 18%).

Another example of thermal manikin application are thermal insulation investigations [15] performed for two variants of the motorcyclist clothing in different weather conditions. The object measured was clothing with lining and membrane as well as clothing without lining but with membrane. Wind speed increase during measurements caused a thermal insulation decrease in the case of clothing with the lining and membrane of about 20%, and 17% for clothing without the lining but with the membrane.

The next example of thermal manikin application was measurement of the thermal comfort of soldiers dressed in bulletproof vests and helmets [16]. Result analysis showed that the different thermal insulation values were dependent on the application of ballistic inserts (hard, soft) and the higher thermal insulation value for the body covered more by the vest.

Another example of research [17] with the use of thermal manikin was examination of medical clothing protecting doctors and nurses against a bacteria propagation. Such clothing should not cause an overheating of the human organism and influence negatively psychometrical abilities. Clothing for the surgery has to be resistant on the blood and bacteria transmission, and at the same time it should be characterized by a water vapor permeability. In this case the values of thermal insulation measured on the thermal manikin were higher than required ones.

A thermal manikin was also used for research done on vests containing PCMs [18]. These were destined for work in a moderate hot environment and contained two kinds of microcapsules: hexadecane and oktadekane. They were characterised by different melting temperatures. The vest covered circa. 20% of the total area of the human body. The incorporation of capsules into the vest structure caused an decrease in the torso temperature of about 0.4 - 1.7 °C. Thermal insulation measured on the thermal manikin indicated the vest into which the mixture of both kinds of capsules was introduced as the better solution. Moreover this vest allowed to absorb the highest heat amount in the longer time period.

In East China [20], jackets filled with duck down and kapok fibres were compared. The results of thermal insulation for the clothing sets examined did not indicate significant differences. Thermal insulation values were confined in the interval 0.28 - 0.36 clo (1 clo = 0.155 m^2K/W).These jackets were classified as clothing protecting against cold.

A thermal manikin was used for the thermal insulation determination of summer and winter Tibetan clothing [19]. Measurements were carried out for 3 kinds of Tibetan clothing: covering the whole human body, with one shoulder uncovered, and with the torso uncovered. Additionally the Tibetan dress was compared with clothing sets elaborated by the American Society of Heating Refrigerating and Air Conditioning Engineering (ASHRAE). The thermal insulation of 3 Tibetan clothing kinds decreased from the first to the last clothing type. Compared to the clothing sets elaborated by ASHRAE, the Tibetan clothing achieved higher values of thermal insulation of about 0.23 clo.

On the basis of the literature review, it was stated that measurements on a thermal manikin performed in static and dynamic conditions show differences in the values of thermal insulation obtained. While walking, the manikin has limited movement possibilities and stays in the same place in space, and owing to such a movement, the results do not take into consideration convection without changing the place. This convection is caused by the movement of hands and legs, whereas the torso and head do not move. Such parts of the human body like the head, chest, back and pelvis create about 42% of the whole body surface area.

During measurements performed on a moving manikin, its movement can be compared to running on a treadmill, and not to the natural body movement [28]. Measurements carried out by Oliveira *et al.* [29] and Anttonen *et al.* [30] show smaller values of thermal insulation for dynamic conditions. Clothing which has ventilation holes in its structure assures additional heat exchange between the body surface and the environment [29]. Heat exchange takes place during movement and is much higher than in the static position. In dynamic conditions the air movement inside the clothing causes the convection to increase and ventilation [30], which means that heat exchange from the body surface occurs, and as a result the thermal insulation of the clothing decreases.

Investigation of a thermal manikin for different clothing sizes indicates an increase in thermal insulation successively the higher the clothing size. Therefore choosing an appropriate clothing size for the user's (thermal manikin) silhouette is a very important problem. Research done by Anttonen *et al.* [30] shows an increase in thermal insulation of about 10% for clothing which was too big by about 4 sizes.

Size influence was also investigated by Chen *at all.* [31]. The authors presented thermal insulation results for tweed trousers, which were about 33% higher for a big size than for a small one; and for jeans trousers, they were about 48% higher than for the smaller size. Thermal

Figure 1. Photo of clothing for a foundry worker.

insulation obtained for more fitted trousers has a trend of diminishing thermal insulation values in the interval 6 – 31%.

The aim of the study of Psikuta *at al.* [32] was to determine the contact area and air gap thickness between clothing and the human body in detail, because these factors influence the thermal properties of clothing.

Materials and measurement methods

Measurements of thermal insulation were made for traditional protective clothing of the same (commercial) construction made of aluminised glass fabric and a new one made of aluminised basalt fabric (***Figure 1***). Under the protective clothing the manikin was dressed in underwear or sometimes not. Traditional cotton underwear was compared with 2 innovative underwear products. Clothing sets which consisted of protective clothing and appropriate underwear covering the upper and lower parts of the manikin body in 2 size variants (small S and medium M) were measured on a thermal manikin in size M. Finally in the first part of the investigation, the clothing assemblies measured were created by two kinds of personalised protective clothing: basalt (BAZ) and glass (SZ), as well as 3 kinds of underwear products (cotton B, thermoactive T, non-flammable finished N) available on the market produced by the Brubeck company. In the second part of the paper, the manikin was dressed in only two variants of aluminised basalt clothing of different constructions (without any underwear).

Measurements of the thermal insulation of appropriate sets of protective clothing and underwear were carried out according to the logistic plan given in ***Table 1*** on the thermal manikin PERNIL (located at the Institute of Textile Architecture of Lodz University of Technology) in a climatic chamber of 20 °C temperature and 43% relative humidity according to PN-EN ISO 15831:2006 [21].

The model of thermal manikin was produced by the Danish PT TEKNIK firm. It consists of 24 segments and has the shape of a woman's body of size m with a movement option [22, 23]. It enabled bending the knees to a 90° angle and their return to 100°. Shoulders can be turned in the interval from 0° to 300° and the head can be rotated to the left and right. Results of the total thermal insulation were registered in tables and could be sent to MS-Excel.

Table 1. *Assemblies of clothing protecting against flame and heat radiation for measurement on a thermal manikin.*

Kind of underwear	Symbol of underwear	Size of underwear	Kind of clothing
Cotton	B	S	Basalt
		M	BAZ
Thermo-active	T	S	Basalt
		M	BAZ
Finished non-flammably	N	S	Basalt
		M	BAZ
Cotton	B	S	Glass
		M	SZ
Thermoactive	T	S	Glass
		M	SZ
Finished non-flammably	N	S	Glass
		M	SZ

According to [21], the total thermal insulation of clothing represents the total thermal insulation which is between the skin and surrounding atmosphere, taking into account clothing layers and the boarding air layer, measured in conditions determined with the use of a non-moving thermal manikin. The total thermal insulation was calculated on the basis of an equation describing the serial model, in which the determination of thermal insulation is obtained on the basis of weighted areas of particular manikin elements [21].

The manikin body was covered by underwear and protective clothing on the segments given in ***Table 2***.

Description of protective clothing based on aluminized basalt and glass fabrics

The model of protective clothing chosen for measurement, consisting of a blouse and trousers (***Figure 1***), was sewn by the IZO-TERM firm in Poland. The commercially produced model contained aluminized glass fabric ST 97 (***Table 3***) and wool lining with non-flammable finishing of symbol 9409/02388 OG. The new model was analogous, but made of different fabric assemblies.

Table 1 presents the basic characteristics of the materials examined, which were the components of the clothing assemblies. The mass per square meter was determined according to Standard EN 12127:1997 [24] and the thickness according to Standard EN ISO 5084:1999 [25].

The blouse has two symmetrical fronts with Velcro and naps. The back is divided into two parts, with a yoke added to the lower part of the back. The sleeves are long, made of one fabric element, with the seam placed on the back part of the sleeve. Trousers have two symmetrical fronts and two symmetrical backs. In the front, naps are placed. Additionally they have braces without a yoke.

In the next step of the research, some modifications were introduced to the commercially sewn basalt protective clothing for a foundry worker offered on the market. Modification of the clothing structure, which defined the final shape of the clothing, is described below:

- adding ventilation chanels,
- rebuilding the structure of clothing patterns by the addition of some elements necessary for integration with clothing sensors of thermal shock,
- individualisation of clothing patterns basing on the 3D clothing design,
- introducing a textronic system monitoring the temperature into the clothing structure.

Then measurements were carried out on two models of protective clothing for a foundry worker (chapter *Influence of user movement on the thermal insulation of clothing, Influence of underwear on the thermal insulation of the clothing set in static conditions*): clothing produced from aluminised basalt fabric fitted to the manikin size (on measure) of the same construction as clothing from aluminised glass fabric produced commercially (called in short – commercially produced clothing from aluminized basalt fabric), and an aluminized basalt clothing prototype with the above-mentioned modifications introduced.

Description of traditional and innovative underwear products

The underwear products investigated, named cotton B, thermoactive T and with flameretardant finishing N, the characteristics of which are given precisely in [26] and ***Table 4***, were in s and m sizes from a unisex collection. Paper [26] also presents thermal insulation values for a manikin dressed only in underwear.

To provide a feeling of physiological comfort at the higher level than in the case of traditional cotton underwear, the selection of appropriate synthetic fibres was made. Therefore the innovative underwear products allowed better air and moisture transportation through textiles than in the case of the application of cotton fibres. The use of a variety of structural parameters of underwear provides a differentiation of thermal insulation values.

Table 2. *Segments of manikin covered by clothing.*

Lp.	Name of segment	Area of segment [m^2]
1	L. Lower leg	0.0975
2	R. Lower leg	0.0975
3	L. Front thigh	0.0858
4	R. Front thigh	0.0858
5	L Back thigh	0.0858
6	R. Back thigh	0.0858
7	Pelvis	0.0558
8	L Back side	0.0408
9	R. Back side	0.0408
10	L. Forearm	0.05
11	R. Forearm	0.05
12	L Upper arm	0.073
13	R. Upper arm	0.078
14	L. Chest	0.07
15	R. Chest	0.07
16	L Back	0.065
17	R. back	0.065

Table 3. *Characteristics of aluminised fabrics and lining fabric used in the protective clothing.*

Lp.	Fabric	Symbol	Mass per square meter, g/m^2	Thickness, mm	Weave
1.	Aluminised glass fabric ST 97	S2	430	0.56	twill
2.	Wool fabric with flame-retardant finishing	WN	566	5.31	
3.	Aluminised basalt fabric	B2	440	0.49	

Creating separate zones of underwear that differ by stitch enables to ensure the comfort of the user. A plated stitch contains two types of yarns in its structure. A Jacquard stitch has links which are characterised by low compressibility and provide additional ventilation in areas of potentially increased sweating. Underwear made by this type of stitch ensures higher air permeability than in the case of a traditional plain knit.

Results and discussion

Influence of underwear size on the thermal insulation of the set of protective clothing with underwear

Figures 2 - 5 present successively results of thermal insulation obtained in the static position of appropriate assemblies of aluminised clothing (made of glass SZ or basalt BAZ fabrics with a wool lining of non-flammable finishing) with 3 types of underwear: thermo-active T, with flame-retardant finishing N, and traditional cotton B, separately for each kind of protective clothing. ***Figures 2*** and ***3*** present results for assemblies with the underwear products in size S.

The highest thermal insulation in both cases (for the aluminized glass SZ and basalt BAZ clothing variants) was observed for clothing assemblies with thermoactive underwear T. For assemblies with the aluminized basalt clothing (***Figure 3***) and appropriate underwear products in size s in two cases (with thermoactive T and cotton underwear B), the values of thermal insulation are slightly higher than in the case of clothing made of aluminised glass fabrics. Analogous graphs prepared for assemblies with the protective clothing and underwear products of size m are presented in ***Figures 4 - 5***.

Comparing the thermal insulation values for sets with thermoactive (T) underwear, it can be noticed that for the aluminized basalt clothing with underwear in size m (BAZTm), the values are of

Table 4. *Characteristics of underwear products, where: Lk - wale count/1 cm; Lr - course count/1 cm.*

Kind of underwear	Symbol of under-wear	Stitch	Mass per square meter, g/m^2	Thickness , mm	Lk/1, cm	Lr/1, cm	Raw material content
Cotton	B	Plain	20	0.81	10	17	100% cotton
Thermo-active	T	Plated plain with jacquard elements	155	0.70	16	18	54%PA, 44%PES, 2% Elastan
With flameretardant finishing	N	Plated plain	158	0.71	15	22	54%Modal Protect, 27% cotton 19%PA

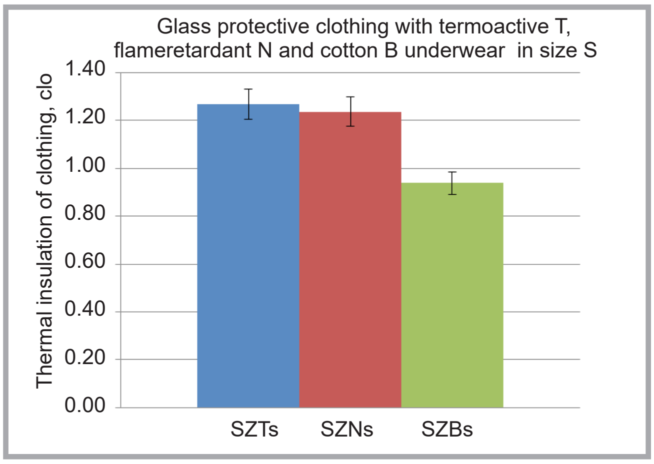

***Figure 2.** Values of thermal insulation for sets of aluminised glass clothing with 3 types of underwear products in size S.*

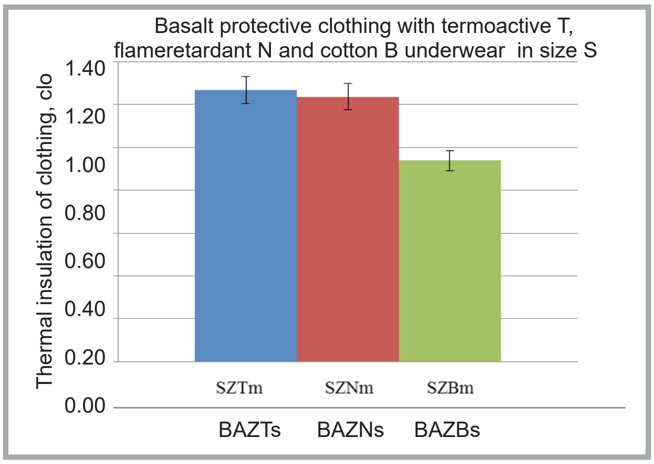

***Figure 3.** Values of thermal insulation for sets of aluminized basalt clothing with 3 types of underwear products in size S.*

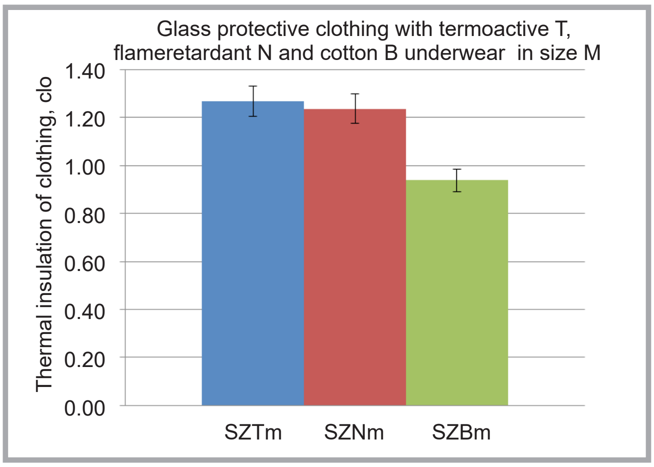

***Figure 4.** Values of thermal insulation for sets of aluminized glass clothing with 3 types of underwear products in size M.*

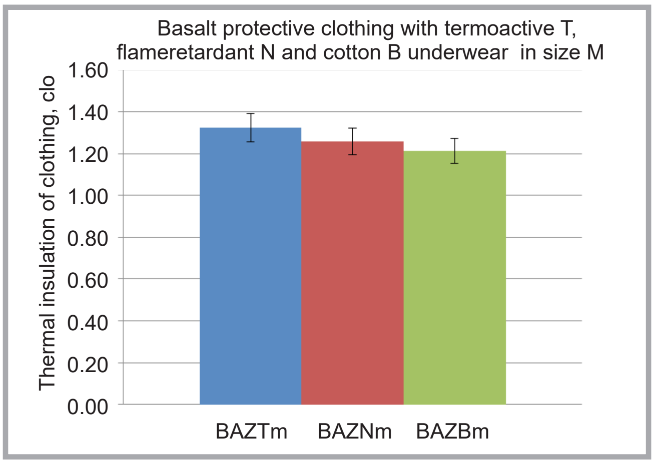

***Figure 5.** Values of thermal insulation for sets of aluminized basalt clothing with 3 types of underwear products in size M.*

a similar level to those for aluminised glass clothing with underwear in size M (SZTm).

On the basis of results from ***Figures 4*** and ***5***, it can also be noticed that in all cases the results of thermal insulation for sets with clothing made with the use of aluminised basalt fabrics are a little higher than those for the sets of clothing made with the use of aluminised glass fabrics. The statement above proves that the assumed thesis of replacement of aluminised glass clothing with aluminized basalt clothing is justified.

Although the underwear with flame-retardant finishing in sets (SZNm, BAZNm) gave fewer lower results than the thermoactive underwear in sets (SZTm, BAZTm), its application is justified by special properties like flame-retardancy. Underwear with flame-retardant finishing induces an increase in protection against harmful factors which can appear during work in a hot environment.

In ***Figures 2 - 5*** it can be observed that in the case of clothing sets with traditional underwear products made of cotton B, the values of thermal insulation are lower than in the case of the application of innovative underwear products.

Table 5 presents mean and standard deviation values for all variants of clothing examined: glass and basalt with 3 variants of underwear products in 2 sizes.

On the basis of results presented in ***Table 5,*** it can be seen that for the sets of clothing made with the use of aluminised glass fabrics, the values of thermal insulation for the sets with thermoactive underwear in two sizes (SZTs) and (SZTm) differ from each other the most (0.16 clo); but in all cases differences are not statistically significant.

In all the cases of protective clothing and underwear, the same tendency was observed, i.e., lower values of thermal insulation when underwear in size s was used than in the case of using underwear in size m. An increase in thermal insulation for sets with underwear in size m depends on a larger amount of air which is placed

***Table 5.** Mean and standard deviation values for sets of clothing and underwear measured.*

Aluminized glass protective clothing with 3 variants of underwear in 2 sizes						
Symbol of clothing set	**SZTs**	**SZTm**	**SZNs**	**SZNm**	**SZBs**	**SZBm**
Mean value [clo]	1.11	1.27	1.12	1.24	0.92	0.94
Standard deviation [clo]	0.01	0.01	0.03	0.02	0.02	0.05
Aluminized basalt protective clothing with 3 variants of underwear in 2 sizes						
Symbol of clothing set	**BAZTs**	**BAZTm**	**BAZNs**	**BAZNm**	**BAZBs**	**BAZBm**
Mean value [clo]	1.17	1.32	0.92	1.26	1.05	1.21
Standard deviation [clo]	0.02	0.01	0.03	0.02	0.03	0.03

between the human skin and underwear layer. Research [13] confirms that the air between clothing layers can improve the thermal insulation of clothing. Often in order to improve insulation, the number of clothing layers is increased. Then, the thickness of the clothing product increases and the bigger amount of stir air ensures better insulation.

The processes of heat exchange through the clothing depend mainly on the values of thermal insulation. Research carried out by Holmer [24] showed that the value of thermal insulation of two-part aluminised protective clothing was 1.48 clo. The author underlined that it depends on the properties of textile materials used in the clothing as well as on the amount of air in the material structure as well as between the particular clothing layers. He pointed out that a significant factor influencing clothing thermal insulation is the amount of air placed between the clothing layers.

Influence of user movement on the thermal insulation of clothing

Additionally in order to state the influence of movement on the thermal insulation of protective clothing, measurements were carried out in both static and dynamic conditions for two kinds of basalt clothing. The clothing models (variants) used for measurement were different not only in the aspect of construction modifications (one-part back, three element sleeves), but also in the degree of fit of clothing to the manikin's body. The commercial clothing was smaller than the prototype. The main aim of investigation in this research step was not only the influence of user movement but also analysis of the fit of the degree influence (size difference) of protective clothing for a foundry worker to the user (in this case – the manikin).

Figure 6, presents results of thermal insulation when the manikin was wearing two variants of protective clothing (commercial clothing and a prototype with modifications measured according to Standard PN-EN ISO 15831:2006 [21] in static and dynamic conditions. To be able to better assess the influence of clothing modifications, both clothing variants were worn without any underwear. We observed the tendency that the thermal insulation of commercial clothing sewn to measure on the manikin was lower in the static position than for the prototype with modifications, which was designed with higher values of fit tolerances.

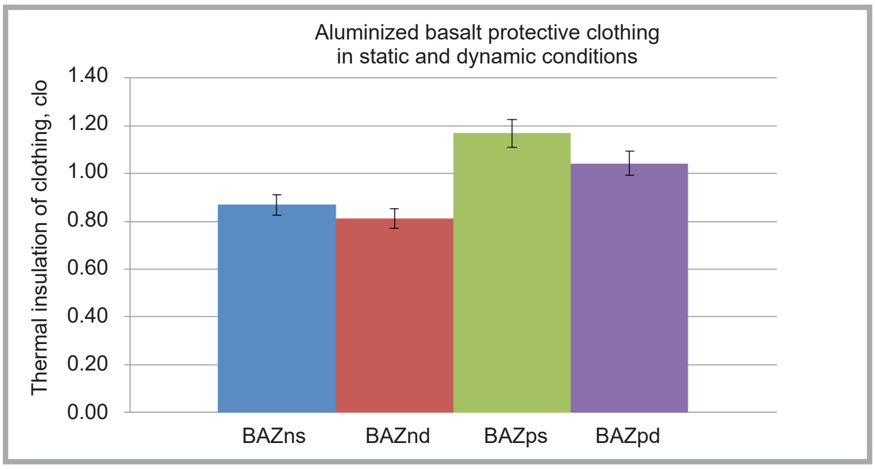

Figure 6. *Thermal insulation of clothing variants made of aluminised basalt fabrics at temperature 20 °C: n – commercial fitting to the thermal manikin size, p – prototype with constructional modifications, s - taken in the static manikin position, d – taken in the dynamic conditions.*

With respect to results of measurements made in dynamic conditions with a walking speed of 15 steps per hour, the thermal insulation value registered was also higher for the prototype than for the commercial clothing. For the dynamic conditions, a decrease in thermal insulation was observed in relation to static conditions for both protective clothing models from aluminized basalt fabric examined. Moreover the results of thermal insulation for the prototype show a bigger difference between the values in static and dynamic conditions. As was mentioned earlier, the modifications introduced into the commercial clothing relied, among others, on placing additional ventilation holes in the clothing structure. Thanks to this solution, during manikin movement, a bigger amount of air is transported from the manikin body to the environment as an effect of the pumping phenomenon. In the commercial clothing which was sewn to measure for the manikin, there was a lack of such ventilation holes; therefore the difference between the thermal insulation for static and dynamic conditions was lower than in the case of the clothing prototype. For commercial clothing this difference was 7%, whereas for the prototype with modifications it was 12%.

Influence of underwear on the thermal insulation of the clothing set in static conditions

Additionally a comparative analysis was carried out for the thermal insulation of commercial basalt protective clothing fitted to the thermal manikin with flame-retardant underwear in size M (from the chapter *Influence of underwear size on the thermal insulation of the set of protective clothing with underwear*) and two variants of basalt protective clothing in the static position (from *Influence of user movement on the thermal insulation of clothing*), i.e., the same basalt protective clothing but without the underwear and a prototype with constructional modifications (also without underwear). The results obtained are presented in ***Figure*** *7*.

For the clothing with underwear, a higher value of thermal insulation is seen. An additional layer of underwear is responsible for the thermal insulation increase for the whole clothing set. On the basis of results obtained for the prototype, a trend of increasing thermal insulation can be supposed (especially if the underwear is taken into account), and the same trend of good efficiency of protection against high temperature and radiation heat.

In ***Table 6***, mean values and standard deviations of thermal insulation values in clo are shown for the variants of clothing made of aluminized basalt fabrics examined: the commercial one and prototype.

Summary

An earlier experiment carried out confirmed that aluminized basalt fabrics used in protective clothing for foundry workers ensure at least the same protection (or slightly better) at a lower cost than for far aluminised glass fabrics [27].

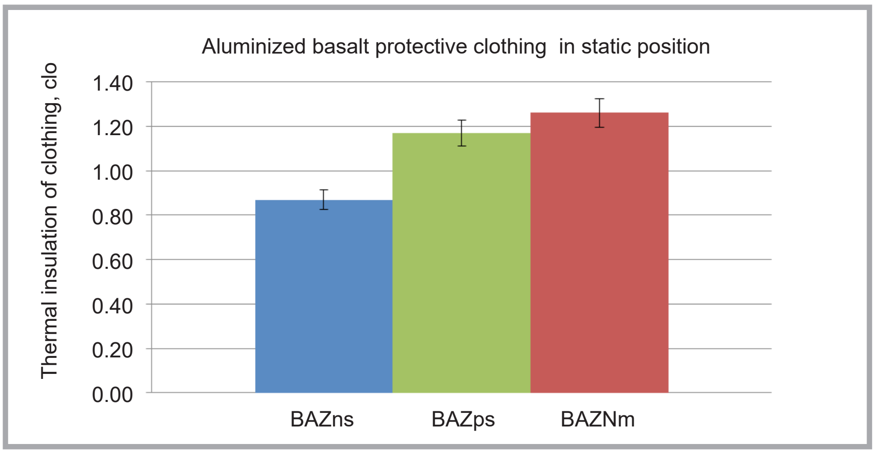

Figure 7. *Thermal insulation of clothing variants made of aluminised basalt fabrics at temperature 20 °C: n – commercial variant fitted to thermal mannikin size, p – prototype with constructional modifications, Nm – commercial variant with nonflammable underwear in size M, s - taken in the static manikin position.*

Table 6. *Mean values and standard deviations of thermal insulation in clo for the variants of clothing examined for a foundry worker: commercial variant n, prototype (p) in static (s) and dynamic (d) conditions, and the commercial variant with underwear.*

Thermal insulation of aluminized basalt clothing					
Symbol	**BAZns**	**BAZnd**	**BAZps**	**BAZpd**	**BAZNm**
Mean value, clo	0.87	0.81	1.17	1.04	1.26
Standard deviation, clo	0.006	0.003	0.003	0.010	0.020

After very careful analysis of measurement results presented, it can be stated that the best variant ensuring appropriate protection [27] and comfort for a foundry worker is the set of clothing made of aluminized basalt fabric with non-flammable finished underwear in size M (BAZNm).

Measurements carried out on a thermal manikin with thermal insulation from protective clothing personalised for the manikin size and with underwear sets covering the upper and lower manikin parts showed that using the bigger size (in this case M size) of underwear gives better results of thermal insulation. The results also suggested that innovative underwear products made of synthetic fibres are a better solution for a foundry worker than traditional cotton ones.

Also observed was the tendency that the thermal insulation for the commercial clothing sewn to measure for the manikin was lower in static and dynamic conditions than for the prototype with modifications, which was designed with higher values of fit tolerances. Therefore we can state that the constructional modifications introduced improved the thermal insulation of clothing.

The research mentioned earlier done by Oliveira *et al*. [29] and Anttonen *et al.* [30], showing a comparison of thermal insulation in static and dynamic conditions, was confirmed in our research performed on two variants of protective clothing: a commercial one and prototype with some modifications. The thermal insulation of the protective clothing was higher in the static position than in the dynamic one.

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