INTRODUCTION

Ballistic protection products simultaneously impose two contradictory requirements: ballistic performance requires a large mass and volume of the product, but at the same time the product must be light and comfortable to wear. The factors that are influencing the energy absorption characteristics of ballistic protection systems depend on the properties of the constituent materials, the design parameters of the textile material, the number of layers of textile material, the density of the material and the impact conditions, such as projectile mass, impact velocity and projectile geometry.

In the last decades, a significant research effort has been made to study the ballistic impact mechanisms of bulletproof vests reinforced with textile structures. The traditional method of improving ballistic characteristics is to increase the number of layers [1–7] or, for some applications, to stitch the layers together with an orthogonal pattern or bias pattern [8–10]. The ballistic performance of bulletproof vests/equipment is influenced by different factors, such as the design and structure of textile/non-textile layers, their

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ANCOVA analysis of penetration force on Kevlar fabrics used for ballistic protective equipment

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ABSTRACT – REZUMAT

ANCOVA analysis of penetration force on Kevlar fabrics used for ballistic protective equipment

The paper aims to highlight the existence of significant differences between the variation of the penetration force of three groups of fabrics used for ballistic protective equipment in the function of the deformation arrow, using the ANCOVA mathematical model with a nominal independent variable and a quantitative independent variable. The model included: the dependent variable (Y) – the variation of the penetration force T(N); nominal independent variable – fabric group; quantitative independent variable – deformation arrow, Δl(mm). This paper analyses the effect of the nominal independent variable and the quantitative independent variable on the penetration force variation, using the ANCOVA model. From the results obtained, through Tests of Between-Subjects Effects, it is observed that the effect of the nominal independent variable “fabric group” is significant and also the effect of the covariate “deformation arrow” is significant. Interpreting the value of Sig < 0.05, it can be concluded that there are significant differences between the variation of the penetration force deformation (alternative hypothesis H1 is accepted). This technique can be used later to model the physical and mechanical properties of fabrics and to select the most appropriate fabrics to meet the requirements of a particular field of use.

Keywords: ANCOVA model, deformation arrow, penetration force, Kevlar fabrics

Analiza forței de străpungere a țesăturilor din Kevlar folosite pentru echipamente de protecție balistică utilizând modelul ANCOVA

Lucrarea și-a propus să evidențieze existența diferențelor semnificative dintre variația forței de străpungere a unor grupe de țesături destinate confectionării echipamentelor de protecție balistică în funcție de săgeata de deformare, utilizând modelul matematic ANCOVA cu o variabilă independentă nominală și o variabilă independentă cantitativă. În cadrul modelului au fost incluse: variabila dependentă (Y) – variația forței de străpungere T(N); variabila independentă nominală – grupa de țesături; variabila independentă cantitativă – săgeata de deformare, Δl(mm). Această lucrare studiază efectul variabilei independente nominale și a variabilei independente cantitative asupra variației forței de străpungere, utilizând modelul ANCOVA. Din rezultatele obținute, prin intermediul Tests of Between-Subjects Effects, se observă că efectul variabilei independente nominale “grupa de țesături” este semnificativ și de asemenea, efectul covariabilei “săgeata de deformare” este semnificativ. Interprețând valoarea Sig < 0.05, se poate concluziona că între variația forței de străpungere există diferențe semnificative în funcție de grupele de țesături studiate și săgeata de deformare (se acceptă ipoteza alternativa H1). Această tehnică poate fi folosită ulterior pentru modelarea proprietăților fizico-mecanice ale țesăturilor și pentru selectarea celor mai adecvate țesături privind satisfacerea cerințelor unui anumit domeniu de utilizare.

Cuvinte-cheie: modelul ANCOVA, săgeata de deformare, forța de străpungere, țesături Kevlar

INTRODUCTION

Ballistic protection products simultaneously impose two contradictory requirements: ballistic performance requires a large mass and volume of the product, but at the same time the product must be light and comfortable to wear. The factors that are influencing the energy absorption characteristics of ballistic protection systems depend on the properties of the constituent materials, the design parameters of the textile material, the number of layers of textile material, the density of the material and the impact conditions, such as projectile mass, impact velocity and projectile geometry.

In the last decades, a significant research effort has been made to study the ballistic impact mechanisms of bulletproof vests reinforced with textile structures. The traditional method of improving ballistic characteristics is to increase the number of layers [1–7] or, for some applications, to stitch the layers together with an orthogonal pattern or bias pattern [8–10]. The ballistic performance of bulletproof vests/equipment is influenced by different factors, such as the design and structure of textile/non-textile layers, their

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number, thickness, specific mass and nature of the raw material [11–15].

In order to improve the ballistic performances of the bulletproof equipment’s, the computational analysis or the mathematical modelling of the different relevant factors/characteristics are frequently used, among which the most important ones are the penetration resistance and the deformation arrow [16–20]. The mechanisms of energy absorption at ballistic speeds are important in ballistic protection [21, 22]. The primary factors that determine the weight needed to stop a projectile are the specific energy absorption, determined by the tenacity and elongation, and the sonic velocity of fibres, determined by the specific modulus, indicating the area of the fabric to be involved in stopping the projectile [23]. Typical bulletproof vests are made from multiple layers of woven fabric, with the degree of protection being increased as the number of fabric layers increases [24]. These layers are assembled into a ‘ballistic panel’, which is then inserted into the ‘carrier’, which is constructed from conventional garment fabrics such as nylon or cotton. The ballistic panel may be permanently sewn into the carrier or maybe removable [25]. Although the overall finished product looks relatively simple in construction, the ballistic panel can be very complex. Even the manner in which the ballistic panels are assembled into a single unit can differ from one product to another [26, 27].

In the constructive technological design of ballistic/bulletproof vest, it is important to know under what conditions the layer structure has maximum/minimum deformation, at what value of the penetration force and what pressure is transmitted to the body during impact. The number and nature of the layers of material in the bulletproof vest directly determine the level of protection provided (according to the NIJ standard), the parameters of comfort, the production of possible traumas or shocks on the human body. In the present paper, the variation of the penetration force and the corresponding elongation for several variants of Kevlar fabric groups were analysed, using the ANCOVA method.

MATERIALS AND METHODS

The combination of layers chosen for the manufacture of individual ballistic protection equipment must primarily ensure the protection of the body against the action of risk factors, low-level trauma and comfort parameters. Kevlar is a material whose manufacture imposes high costs. The need to use a large number of layers has highlighted the need to combine it with other materials when conditions of use allow. The study included the use of Kevlar layers (5 layers) and their combination with 1 or 2 metallic gauze layers, tested for penetration force and deformation arrow. The tested ballistic packages have the structure and characteristics presented in the table. Ballistic performance of the three variants of Kevlar/metallic gauze materials was tested in the Testing Laboratory for Ballistic and Pyrotechnic Protection (LIPBP) within the Scientific Research Centre for Defense CBRN and Ecology in accordance with the NIJ 01.01 04/2000 standard, using the 9 mm Jericho weapon. Experimental research was performed on the Marshall Stability Tester. Following the tests performed, the values recorded for the penetration force and the deformation arrow were introduced as variables in the ANCOVA mathematical model.

ANCOVA is a statistical procedure that enables one to compare groups on some quantitative dependent variable while simultaneously controlling for quantitative independent variables [28, 29]. Thus, ANCOVA combines both qualitative and quantitative independent variables. ANCOVA is used because the inclusion of the covariate in the model can increase power to detect group differences and the precision of estimates [30, 31]. With respect to the design, ANCOVA models explain the dependent variable by combining categorical (qualitative) independent variables with continuous (quantitative) variables [32, 33]. The ANCOVA method belongs to a larger family of models called GLM (Generalized Linear Models), as well as Linear Regression and Variance Analysis (ANOVA), with applications in different fields: medicine, psychology, sociology, engineering [34]. AN-OVA checks the correlation between a dependent variable and the covariate independent variables and removes the variability from the dependent variable that can be accounted for by the covariates. Analysis of covariance models combines analysis of variance with regression analysis techniques. There are special extensions to ANCOVA calculations to estimate parameters for both categorical and continuous variables [35, 36]. However, ANCOVA models can also be calculated using multiple regression analysis using a design matrix with a mix of dummy-coded qualitative and quantitative variables [37].

RESULTS AND DISCUSSIONS

The results obtained for testing the materials for penetration force and deformation arrow are presented in Table 2. The processing is performed in the SPSS program (Statistical Package for the Social Sciences) using the stages and statistical tests specific to the ANCOVA regression model following several steps.

Systematization and processing of experimental data

An ANCOVA regression model is constructed with a nominal independent variable and a quantitative
variable in which: the dependent variable \( Y \) – the variation of the penetration force \( F \) (N); nominal independent variable – fabric group (G1 – 5 layers Kevlar, G2 – 5 layers Kevlar + 1 layer of metallic gauze, G3 – 5 layers Kevlar + 2 layers of metallic gauze; quantitative independent variable: deformation arrow, \( D \) (mm). Frequency distributions for the variation of the penetration force, \( T \) [N] depending on the studied fabric groups are represented in the Boxplot diagrams from figures 1–3.

These diagrams include the most important statistical characteristics: minimum, maximum, median values, the lower quartile Q1 which delimits the smallest 25% of the measured values and the upper quartile Q3 which delimits the largest 25% of the measured values. A box plot (or box-and-whisker plot) shows the distribution of quantitative data in a way that facilitates comparisons between variables or across levels of a categorical variable. The box shows the quartiles of the dataset while the whiskers extend to show the rest of the distribution, except for points that are determined to be “outliers” using a method that is a function of the inter-quartile range.

Hypothesis formulation

H0: no significant differences between the variation of the penetration force depending on the groups of fabrics studied and the deformation arrow.

H1: there are significant differences between the variation of the penetration force depending on the groups of fabrics studied and the deformation arrow.

Construction and interpretation of the regression model

Within the ANCOVA regression model, the nominal independent variable “fabric group” has 3 variants, so two dummy variables will be constructed. The reference variant (D1, D2=0) will be the one consisting of

| Fabric groups | Penetration force \( T \) (N) | Deformation arrow \( D \) (mm) | Fabric groups | Penetration force \( T \) (N) | Deformation arrow \( D \) (mm) | Fabric groups | Penetration force \( T \) (N) | Deformation arrow \( D \) (mm) |
|---------------|------------------|------------------|---------------|------------------|------------------|---------------|------------------|------------------|
| G1            | 985.80           | 32.60            | G2            | 842.70           | 27.60            | G3            | 732.50           | 18.90            |
|               | 978.60           | 31.80            |               | 834.50           | 27.10            |               | 725.80           | 17.80            |
|               | 981.20           | 31.90            |               | 828.90           | 27.50            |               | 729.40           | 16.80            |
|               | 995.40           | 30.10            |               | 831.80           | 26.80            |               | 726.30           | 18.90            |
|               | 973.70           | 31.30            |               | 837.50           | 27.50            |               | 730.50           | 19.00            |
|               | 977.40           | 31.60            |               | 837.30           | 26.80            |               | 731.90           | 18.50            |
|               | 969.70           | 32.10            |               | 840.40           | 28.10            |               | 733.70           | 18.70            |

Table 2

Fig. 1. Boxplot diagram for group G1

Fig. 2. Boxplot diagram for group G2

Fig. 3. Boxplot diagram for group G3
5 layers of Kevlar; therefore, all interpretations will be made in comparison to this category. The transformation into dummy variables is shown in table 3.

The ANCOVA model is defined by the relation:

\[ Y = \alpha_0 + \alpha_1 D_1 + \alpha_2 D_2 + \beta_1 X_1 + \varepsilon \] (1)

Conditional average:

\[ M(Y/D) = \alpha_0; \quad D_1, D_2 = 0; \quad M(Y/D) = (\alpha_0 + \alpha_2) + \beta_1 X_1; \quad D_1 = 1, D_2 = 0. \]

The Levene’s test is used to test the homogeneity of the variation within the model. Levene test result \( F(2.18) = 1.807, \text{Sig.} = 0.193 \) (\( p < 0.05 \)) is statistically insignificant, therefore, the homogeneity condition of the variants is met. The effect of the nominal independent variable “fabric group” is significant, \( F(2.17) = 410.790, \text{Sig.} = 0.000, p < 0.05 \) and also, the effect of the covariate “deformation arrow” is significant, \( F(1.17) = 2.676, \text{Sig.} = 0.020, p < 0.05 \), as seen in table 4.

Also, the evaluation of the impact of the independent variables on the dependent variable based on the Type III analysis, shows that the probability \( F \) is much stronger for the fabric group \( (F = 410.790) \), compared to the tear deformation arrow \( (F = 2.676) \) on the variation penetration force.

The graph of the ANCOVA model is presented in figure 4, covariates appearing in the model are evaluated at the following values: deformation arrow = 25.8762 mm. The results show that the penetration force estimates for the three groups of fabrics are statistically related to the deformation arrow. Thus, as we introduce one or two layers of metallic gauze, the penetration force decreases in proportion to the deformation arrow.

The coefficients of the ANCOVA model are calculated in table 4. The model estimates are: \( \alpha_0 = 273.628; \quad \alpha_1 = -40.037; \quad \alpha_2 = 49.167; \quad \beta_1 = 22.166. \)

The regression model is:

\[ Y = 273.628 - 40.037D_1 + 49.167D_2 + 22.166X_1 \] (2)

Model interpretation:

a) \( \alpha_0 = 273.628, \quad D_1, D_2 = 0 \), represents the average value estimated for the variation of the penetration force depending on the group of G1 fabrics and the deformation arrow;

b) \( \alpha_0 + \alpha_1 = 273.628 - 40.037 = 233.591 \) represents the average value estimated for the variation of the penetration force depending on the group of G2 fabrics and the deformation arrow;
c) $\alpha_0 + \alpha_2 = 273.628 + 49.167 = 322.795$ represents the average value estimated for the variation of the penetration force depending on the group of G3 fabrics and deformation arrow;

d) $\beta_1 = 22.166$ shows the variation of the penetration force for the fabrics from 5 layers of Kevlar in the conditions in which the deformation arrow increases.

Interpreting value $\text{Sig} < 0.05$ from table 5, it can be concluded that between the variation of the penetration force there are significant differences depending on the groups of fabrics studied and the deformation arrow (alternative hypothesis $H_1$ is accepted).

Verification of the ANCOVA model involves a series of econometric modelling steps, such as: testing hypotheses on errors; homoscedasticity; normality; error autocorrelation and collinearity testing of independent variables.

a) Testing hypotheses on errors, $M(e) = 0$ (zero error average)

$H_0: M(e) = 0; H_1: M(e) \neq 0$

The Student t test for errors (Unstandardized Residual), presented in table 6, is applied, from which it is observed that the value $\text{Sig} = 1$ ($p > 0.05$), so the null hypothesis $H_0$ is accepted, whereby the average of the errors is 0.

b) Homoscedasticity, $V(e_i) = \sigma^2$ (error variant is equal to dispersion)

$H_0$: the correlation coefficient is insignificantly different from 0 (null hypothesis of the Student’s t test)

$H_1$: the correlation coefficient is significantly different from 0 (the null hypothesis of the Student’s t test is rejected).

A nonparametric correlation test is applied between the estimated errors and the dependent variable, the Spearman correlation coefficient and the Student test are calculated for this coefficient, according to table 7.

Because the values of $\text{Sig}$ of Student’s t test for correlations: Penetration force $T$ (N) – estimated errors $D_1$ – estimated errors $D_2$ – estimated errors $D_l$ (mm) are greater than 0.05, the null hypothesis of the Student test is rejected, so the model is not homoscedastic.

c) Normalcy of errors, $e_i \sim N(0, \sigma^2)$

The testing of the normality of the error distribution is done with the non-parametric Kolmogorov-Smirnov test or by the graphical procedure in the form of a histogram. As can be seen from table 8, the value $\text{Sig} = 0.970$ is higher than the critical value $p = 0.05$, so the normality hypothesis $H_0$ is accepted. From the error distribution, presented in figure 5 it is observed that the values are not normally distributed, they do not follow the distribution law described by the Gauss Laplace curve.

d) Error autocorrelation testing, $cov (e_i, e_i)$

$H_0$: $\rho = 0$ (errors are not autocorrelated); $H_1$: $\rho \neq 0$ (errors are autocorrelated)

The verification is done with the Durbin Watson test, according to table 9.

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### Table 5

| Model 1 | Unstandardized coefficients | Standardized coefficients | $t$ | $\text{Sig.}$ |
|---------|-----------------------------|---------------------------|-----|---------------|
| (Constant) | 273.628 | 85.092 | - | 3.216 | 0.005 |
| D1 | -40.037 | 12.815 | -0.191 | -3.124 | 0.006 |
| D2 | 49.167 | 36.769 | 0.227 | 1.337 | 0.029 |
| $\Delta l$ (mm) | 22.166 | 2.663 | 1.228 | 8.323 | 0.000 |

### Table 6

| One-Sample Test | Test Value = 0 |
|-----------------|----------------|
| $t$ | df | Sig. (2-tailed) | Mean Difference | 95% Confidence Interval of the Difference |
|----------------|-----|----------------|-----------------|----------------------------------|
| Unstandardized Residual | 0.000 | 20 | 1.000 | 0.000 | $-1.8991$ | $1.8991$ |
According to the literature, it is found that the value obtained is in the range $(d_l, 4 - d_u)$, which leads to the acceptance of the null hypothesis (errors are not autocorrelated).

e) Testing the collinearity of independent variables
In practice, the identification of the collinearity of independent variables is done by different methods. Using the SPSS package, collinearity can be detected based on two indicators: Tolerance and VIF (Variance Inflation Factor), presented in table 10. In practice, it is considered that a VIF value > 10 indicates the presence of collinearity. If the tolerance indicator, $TOL = 1$ there is no collinearity, and if $TOL = 0$ we are in the extreme situation of perfect collinearity.

It is observed from table 10, that the VIF indicator has a high value between 4.410 and 25.797, which indicates

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The value of the Durbin-Watson test $DW = 2.091$ is compared with the calculated value of the test $(d_l, d_u)$. The value obtained is in the range $(d_l, d_u)$, which leads to the acceptance of the null hypothesis (errors are not autocorrelated).
that there is collinearity between the dummy variables D1, D2 and the quantitative independent deformation arrow variable, \( \Delta l \) (mm), used in the model.

**CONCLUSIONS**

The paper highlights the existence of significant differences between the variation of the penetration force in the function of the deformation arrow. By analysing the presented data, it can be remarked that the use of G1 layers structure ensures the product a medium elongation, determined by a force and pressure of low values, while the use of Kevlar layers combined with metallic gauze (G2 and G3 layers structure) generates similar results with the first one, but with significantly higher values in terms of puncture strength and pressure.

The ANCOVA model allows us to evaluate the homogeneity of a statistical population by separating and testing the effects caused by the factors considered.

Through Tests of Between-Subjects Effects, it is observed that the effect of the nominal independent variable “Fabric group” is significant, \( F(2.17) = 410,790, \text{Sig.} = 0.000, p < 0.05 \) and also the effect of the covariate “deformation arrow” is significant, \( F(1.17) = 2.676, \text{Sig.} = 0.020, p < 0.05 \). Interpreting the value of \( \text{Sig} < 0.05 \), it can be concluded that between the variation of the penetration force there are significant differences depending on the groups of fabrics studied (null hypothesis \( H_0 \) is rejected). The properties of the estimators of the regression model parameters were verified through specific tests and allowed the construction of the ANCOVA model with a nominal independent variable and a quantitative independent variable. The ANCOVA model shows that the variation of the penetration force is significantly influenced of the nominal independent variable “fabric group”, \( F(2.17) = 410,790, \text{Sig.} = 0.000, p < 0.05 \), as well as by the effect of the covariate „deformation arrow”, \( F(1.17) = 2.676, \text{Sig.} = 0.020, p < 0.05 \).

**REFERENCES**

[1] Öberg, E.K., Dean, J., Clyne, T.W., *Effect of inter-layer toughness in ballistic protection systems on absorption of projectile energy*, in: Int. J. Impact Eng., 2015, 76, 75–82

[2] Yang, Y., Chen, X., *Investigation of energy absorption mechanisms in a soft armor panel under ballistic impact*, In: Text. Res. J., 2017, 87, 20, 2475–286

[3] Yang, Y., Chen, X., *Investigation on energy absorption efficiency of each layer in ballistic armour panel for applications in hybrid design*, In: Compos. Struct., 2017, 164, 1–9

[4] Zohdi, T.I., *Modeling and simulation of progressive penetration of multilayered ballistic fabric shielding*, In: Comput. Mech., 2002, 29, 1, 61–67

[5] Joo, K., Kang, T.J., *Numerical analysis of energy absorption mechanism in multi-ply fabric impacts*, In: Text. Res. J., 2008, 78, 7, 561–576

[6] Cunniff, M., Auerbach, M., Vetter, E., Sikkema, D.J., *High performance M5 fiber for ballistics/structural composites*, National Research Council (U.S.), The National Academies Press, 2004

[7] Cheeseman, B.A., Bogetti, T.A., *Ballistic impact into fabric and compliant composite laminates*, In: Compos. Struct., 2003, 35, 18, 161–173

[8] Armellino Jr., R.A., Armellino, S.E., *Ballistic Material for Flexible Body Armor and the Like*, US Patent No. 4522871, June 11, 1985

[9] Dunbavand, I.E., *Flexible Armor*, US Patent No. 4608717, September 2, 1986

[10] Harpell, G.A., Palley, I., Kavesh, S., Prevorsek, D.C., *Ballistic-resistant Fine Weave Fabric Article*, US Patent No. 4737401, April 12, 1988

[11] Medvedovski, E., *Ballistic performance of armour ceramics: Influence of design and structure*. Part 2, Ceram 2010, 36, 2117–2127

[12] Goncalves, D.P., de Melo, F.C.L., Klein, A.N., Al-Qureshi, H.A., *Analysis and investigation of ballistic impact on ceramic/metal composite armour*, In: Int. J. Mach., 2004, 44, 307–316

[13] Liu, S., Wang, J., Wang, Y., Wang, Y., *Improving the ballistic performance of ultrahigh molecular weight polyethylene fiber reinforced composites using conch particles*, In: Mater. Des., 2010, 31, 1711–1715

[14] Stopforth, R., Adali, S., *Experimental study of bullet-proofing capabilities of Kevlar, of different weights and number of layers, with 9 mm projectiles*, In: Def. Technol., 2019, 15, 186–192

[15] Puran, S., Vikas, M., Priyavart, L., *Analysis of composite materials used in bullet proof vests using fem technique*, In: Int. J. Eng. Res., 2013, 4, 5, 1789–1796

[16] Barauskas, R., Abratiene, A., *Computational analysis of impact of a bullet against the multilayer fabrics in LS-DYNA*, In: Int. J. Impact Eng., 2007, 34, 1286–1305

[17] Duan, Y., Keefe, M., Bogetti, T.A., Cheeseman, B.A., *Modeling the role of friction during ballistic impact of a high-strength plain-weave fabric*, In: Compos. Struct., 2005, 68, 331–337

[18] Ramaihaa, G., Chennaiah, R., Satyanarayaranaarao, G., *Investigation and modeling on protective textiles using artificial neural networks for defense applications*, In: Mater. Sci. Eng. B, 2010, 168, 100–105

[19] Zelelew, T.M., Koricho, E.G., *Design and Analysis of Bullet Resistance Jacket Projectile Penetration: Reviews*, In: Mater. Sci. Eng. B, 2019, 23, 1–5

[20] Stopforth, R., Adali, S., *Full metal jacket projectile penetration analysis of Kevlar only bulletproof vest*, In: Proceedings of 3rd International Conference on Composites, Biocomposites and Nanocomposites, 2018, South Africa, 98–106

[21] Glauck, D.H., Muller, K.E., *Adjusting power for a baseline covariate in linear models*, In: Stat. Med., 2003, 22, 2535–2551
[22] Avadanei, M., Dulgheriu, I., Radu, C.D., Virtual prototyping design of bulletproof vests, In: Industria Textila, 2012, 63, 6, 290–295
[23] Austin, P.C., An introduction to propensity score methods for reducing the effects of confounding in observational studies, In: Multivariate Behav. Res., 2011, 46, 3, 399–424
[24] Dulgheriu, I., Avadanei, M., Badea, S., Safta, I., Experimental research on establishing the level of bullets protection for a ballistic protection structure, In: Industria Textila, 2012, 63, 4, 198–203
[25] Lai, K., Kelley, K., Accuracy in parameter estimation for targeted effects in structural equation modeling: Sample size planning for narrow confidence intervals, In: Psychol. Methods, 2011, 16, 127–148
[26] Liu, X.S., Sample size and the width of the confidence interval for mean difference, In: Br. J. Math. Stat. Psychol., 2009, 62, 201–215
[27] Baguley, T., Understanding statistical power in context of applied research, In: Appl. Ergon., 2004, 35, 73–80
[28] Miller, G.A., Chapman, J.P., Misunderstanding Analysis of Covariance, In: J. Abnorm. Psychol., 2001, 110, 40–48
[29] Hristian, L., Ostafe, M.M., Manea, L.R., Apostol, L.L., Study of Mechanical Properties of Wool Type Fabrics using ANCOVA Regression Model, In: International Conference on Innovative Research (ICIR Euroinvent), Book Series: IOP Conference Se-ries-Materials Science and Engineering 2017, 209, 012075
[30] Engqvist, L., The mistreatment of covariate interaction terms in linear mode analyses of behavioral and evolutionary ecology studies, In: Anim. Behav., 2005, 70, 967–971
[31] Hristian, L., Sandu, A.V., Manea, L.M., Tulbure, E.A., Earar, K., Analysis of the Principal Components on the Durability and Comfort Indices of the Fabrics Made of Core-coating Filament Yarns, In: J. Chem., 2015, 66, 3, 342–347
[32] Singh, M., Bai, P., Multiple Regression Analysis Using ANCOVA in University Model, In: Int. J. Appl. Phys. Math., 2013, 3, 5, 336–340
[33] Manea, L.R., Hristian, L., Ostafe, M.M., Apostol, L.L., Sandu, I., Analysis of Characterization Indexes for Worsted Fabrics Type Using Correlation Method as a Statistical Tool, In: Rev. de Chim., 2016, 67, 9, 1758–1762
[34] Rutherford, A., Anova and Ancova: A GLM Approach, 2nd Edition Hoboken, NJ: John Wiley and Sons, 2011
[35] Muhammad, M., Li, N.-W., Muhammad, S.A., Muhammad, K.M., Investigation of various factors affecting the coefficient of friction of yarn by using Taguchi method, In: Industria. Textila, 2019, 70, 3, 211–215, http://doi.org/10.35530/IT.070.03.1555
[36] Hristian, L., Ostafe, M.M., Manea, L.R., Leon, A.L., The study about the use of the natural fibres in composite materials, In: Modtech International Conference – Modern Technologies in Industrial Engineering IV, PTS 1–7, Book Series: IOP Conference Series-Materials Science and Engineering 2016, 145, 032004
[37] Haji, A., Nasiriboroumand, M., Statistical study of the effect of metallic mordants on tensile strength of wool, In: Industria Textila, 2018, 69, 6, 511–518, http://doi.org/10.35530/IT.069.06.1598

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