Study of Mechanical Properties of Wool Type Fabrics using ANCOVA Regression Model

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Abstract. The work has achieved a study on the variation of tensile strength for the four groups of wool fabric type, depending on the fiber composition, the tensile strength of the warp yarns and the weft yarns technological density using ANCOVA regression model. ANCOVA 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. Regarding design, ANCOVA models explain the dependent variable by combining categorical (qualitative) independent variables with continuous (quantitative) variables. There are special extensions to ANCOVA calculations to estimate parameters for both categorical and continuous variables. 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.

1. Introduction

Analysis of covariance models combine analysis of variance with techniques from regression analysis. With respect to the design, ANCOVA models explain the dependent variable by combining categorical (qualitative) independent variables with continuous (quantitative) variables [1-3]. There are special extensions to ANOVA calculations to estimate parameters for both categorical and continuous variables. ANCOVA models can however, also be calculated using multiple regression analysis using a design matrix with a mix of dummy-coded qualitative and quantitative variables [4,5]. In the latter approach, ANCOVA is considered as a special case of the General Linear Model (GLM) framework [6]. The ANCOVA is most useful in that it explains an ANOVA's within-group variance, and controls confounding factors. Firstly, the analysis of variance splits the total variance of the dependent variable into: variance explained by the independent variable (also called between groups variance) and unexplained variance (also called within group variance).

The ANCOVA looks at the unexplained variance and tries to explain some of it with the covariate(s). Thus it increases the power of the ANOVA by explaining more variability in the model [7-9]. This also makes the ANCOVA the model of choice when analyzing semi-partial correlations in an experiment, instead of the partial correlation analysis which requires random data [10-12]. The one-way ANCOVA (analysis of covariance) can be thought of as an extension of the one-way ANOVA to incorporate a covariate. Like the one-way ANOVA, the one-way ANCOVA is used to determine whether there are any significant differences between two or more independent (unrelated) groups on a
dependent variable [12-14]. However, whereas the ANOVA looks for differences in the group means, the ANCOVA looks for differences in adjusted means (i.e., adjusted for the covariate) [15-17]. As such, compared to the one-way ANOVA, the one-way ANCOVA has the additional benefit of allowing you to "statistically control" for a third variable (sometimes known as a "confounding variable"), which you believe will affect your results [18-20]. ANCOVA is a model that relies on linear regression wherein the dependent variable must be linear to the independent variable. The origins of MANCOVA as well as ANOVA stem from agriculture where the main variables are concerned with crop yields.

On the other hand, regression is also a statistical tool which is available in many variants. Its variants include the linear regression model, simple linear regression, logistic regression, nonlinear regression, nonparametric regression, robust regression, and stepwise regression [21-23]. Regression is the relationship of a dependent variable and independent variable to each other. In this model, there is one dependent variable and one or more independent variables. There is also an effort to understand the change of the values of the dependent variable due to changes in one of the independent variants. In this situation, the other independent variants remain fixed [23-26].

2. Experimental part

2.1. Materials and methods

The study was conducted on woven materials made of combed wool type yarns used for manufacturing outwear clothing, on 24 articles. The variation limits of the composition and structural characteristics for the tested woven materials are indicated in Table 1.

| Variant code | Fibrous composition | Yarn count | Nm_warp | Nm_weft | Fabric structure |
|--------------|---------------------|------------|---------|---------|-----------------|
| A3           | 100% Wool           | balanced   | 52/2    | 52/2    | D2/2            |
| A4           |                     |            | 52/2    | 52/2    | plain           |
| A7           |                     | Nm_warp=Nm_weft | 48/2    | 48/2    | D2/2            |
| A10          | 100% Wool           |            | 48/2    | 48/2    | crepe           |
| A1           |                     |            | 40/2    | 24/1    | D2/2            |
| A8           |                     | Nm_warp≠Nm_weft | 48/2    | 30/1    | D2/1            |
| A23          |                     |            | 56/2    | 37/1    | plain           |
| B1           |                     |            | 64/2    | 64/2    | P6/6            |
| B3           |                     |            | 60/2    | 60/2    | D2/2            |
| B12          |                     |            | 52/2    | 52/2    | Plain           |
| B14          |                     | Nm_warp=Nm_weft | 48/2    | 48/2    | D2/2            |
| B7           |                     |            | 52/2    | 52/1    | D2/1            |
| B11          |                     | Nm_warp≠Nm_weft | 52/2    | 30/1    | D2/1            |
| B15          |                     |            | 64/2    | 37/1    | Plain           |
| C2           |                     |            | 60/2    | 60/2    | Plain           |
| C3           |                     |            | 60/2    | 60/2    | D2/2            |
| C7           |                     |            | 52/2    | 52/2    | D2/2            |
| C1           |                     |            | 56/2    | 37/1    | D2/1            |
| C4           |                     |            | 52/2    | 52/1    | D2/1            |
| C5           |                     |            | 56/2    | 37/1    | D2/1            |
| D1           |                     |            | 64/2    | 64/2    | D2/1            |
| D3           |                     |            | 64/2    | 64/2    | Plain           |
| D7           |                     |            | 60/2    | 60/2    | D2/2            |
| D10          |                     |            | 52/2    | 52/2    | D2/1            |
The tensile testing was performed using an H 1K-S UTM Tinius Olsen (Hounsfield) testing machine, with a 1 kN load cell. The tests were done accordingly to standard (SR EN ISO 13934-1:2002) on both directions – weft and warp [26].

3. Results and discussions

3.1. Collection, systematization and processing of experimental data

The Based on the experimental data, the following variables were included in the ANCOVA regression model:
- dependent variable (Y) is tensile strength variance, $P_{warp}$ (daN);
- nominal independent variable is group of woven fabrics depending on fiber composition (100% Wool; 60% PES + 40% CELO; 45% Wool + 55% PES; 45% Wool + 52% PES + 3% Dorlastan) – three dummy variables $D_1$, $D_2$ respective $D_3$;
- quantitative independent variables ($X_1$ respective $X_2$) are warp yarns tensile strength $P_{warp}$ (daN) and weft yarns technological density $D_{weft}$ (yarns/10cm).

3.2. Hypothesis formulation

$H_0$: There are no significant differences between tensile strength values of woven fabrics depending of fiber composition, warp yarns tensile strength $P_{warp}$ (daN) and weft yarns technological density $D_{weft}$ (yarns/10cm);
$H_1$: There are significant differences between tensile strength values of woven fabrics depending of fiber composition, warp yarns tensile strength $P_{warp}$ (daN) and weft yarns technological density $D_{weft}$ (yarns/10cm).

3.3. Formulation of the regression model

The nominal independent variable “fiber composition” has 4 categories, so it can be built three dummy variables called alternative variables. Fabrics to which we relate ($D_1$, $D_2$, $D_3 = 0$) will be made of 100% wool. Therefore, all the performances will be made in comparison with this group of fabrics.

The transformation in the dummy variables is summarized in table 2.

| Group | $D_1$ | $D_2$ | $D_3$ | The fiber composition |
|-------|-------|-------|-------|-----------------------|
| B     | 1     | 0     | 0     | 45% wool + 55% PES    |
| C     | 0     | 1     | 0     | 45% wool + 52% PES + 3% Dorlastan |
| D     | 0     | 0     | 1     | 60% PES + 40% Celo    |
| A     | 0     | 0     | 0     | 100% wool             |

The ANCOVA model with three dummy variables is defined as relation 1:

$Y = a_0 + a_1 D_1 + a_2 D_2 + a_3 D_3 + b_1 X_1 + \epsilon$ (1)

The regression, as a conditioned mean, has the following forms:

$M(Y/D) = a_0 + b_1 X_1 ; D_1, D_2, D_3 = 0$ (2)

for tensile strength variance of 100% wool woven fabrics;

$M(Y/D) = (a_0 + a_1) + b_1 X_1 ; D_1 = 1 ; D_2, D_3 = 0$ (3)

for variance of tensile strength of 45% Wool + 55% PES woven fabrics;

$M(Y/D) = (a_0 + a_2) + b_1 X_1 ; D_2 = 1 ; D_1, D_3 = 0$ (4)

for tensile strength variance of 45% Wool + 52% PES + 3% Dorlastan woven fabrics;

$M(Y/D) = (a_0 + a_3) + b_1 X_1 ; D_3 = 1 ; D_1, D_2 = 0$ (5)

for tensile strength variance of 60% Pes + 40% Celo woven fabrics.

ANCOVA model coefficients are calculated in Table 3.

The estimators and the estimates of the model are defined similar to previous models. Model estimates:
The estimated regression model has the form:

\[ Y = 29,637 + 45,874D_1 + 45,522D_2 - 25,955D_3 + 0.014D_{\text{weft}} \]

### Table 3 ANCOVA model Coefficients\(^a\).

| Model | Unstandardized Coefficients | Standardized Coefficients | t | Sig. |
|-------|-----------------------------|---------------------------|---|------|
|       | B                           | Std. Error                | Beta |      |      |
| (Constant) | 29.637                     | 9.543                     | 3.106 | 0.006 |
| D1    | 45.874                     | 4.160                     | 0.701 | 11.027| 0.000 |
| D2    | 45.522                     | 4.337                     | 0.663 | 10.497| 0.000 |
| D3    | -25.955                    | 4.706                     | -0.325| -5.515| 0.000 |
| D\text{weft (yarn/10cm)} | 0.014                     | 0.039                     | 0.020 | 0.365 | 0.719 |
| (Constant) | 32.960                     | 2.771                     | 11.896| 0.000 |
| D1    | 46.283                     | 3.918                     | 0.707 | 11.812| 0.000 |
| D2    | 45.957                     | 4.078                     | 0.669 | 11.268| 0.000 |
| D3    | -26.058                    | 4.595                     | -0.327| -5.671| 0.000 |

\(a\). Dependent Variable: \(P_{warp}\) (daN)

### 3.4. Interpretation

a) \(a_0 = 29.637\) means the average estimated value for the tensile strength of fabrics made of 100% \textit{wool} while the tensile strength of the warp yarns and the weft yarns technological density should be coded with 0 (\(X_1 = 0\)).

b) \(a_0 + a_1 = 29.637 + 45.874 = 75.511\) means the average estimated value for the tensile strength of the fabrics made of 45\% \textit{wool} +55\% \textit{PES} while the tensile strength of the warp yarns and the weft yarns technological density should be coded with 0 (\(X_1 = 0\)).

c) \(a_0 + a_2 = 29.637 + 45.522 = 75.159\) means the average estimated value for the tensile strength of the fabrics made of 45\% \textit{wool}+52\% \textit{PES}+3\% \textit{Dorlastan} while the tensile strength of the warp yarns and the weft yarns technological density should be coded with 0 (\(X_1 = 0\)).

d) \(a_0 + a_3 = 29.637 - 25.955 = 3.682\) means the average estimated value for the tensile strength of the fabrics made of 100\% \textit{PES} while the tensile strength of the warp yarns and the weft yarns technological density should be coded with 0 (\(X_1 = 0\)).

e) \(b_1\) shows the variation in tensile strength of woolen fabrics as long as the tensile strength of the warp yarns and technological density of the weft yarns increase themselves with a unit.

It results from the coefficients table that sig.is < 0.05 (with the exception of sig.of \(D_{\text{weft (yarns/10 cm)}}\), the value being 0.719).

Although sig.for \(D_{\text{weft (yarns/10cm)}}\) exceeds the value of 0.05 (which shows that the density of the weft yarns does not significantly influence the dependent variable) has not been ejected during the Backward processing method (table 4).

Regression is the method for forecasting and prediction of a continuous outcome. It is the method to use for the continuous outcome and is based on one or more continuous predictor variables.

Interpreting the sig value it can be concluded that there are significant differences between the values of the tensile strength of the fabrics according to the composition of the fiber, the tensile strength of the warp yarns \(P_{warp}\) (daN) (it is rejected the null hypothesis Ho).
Table 4. Variables Entered/Removeda.

| Model | Variables Entered | Variables Removed | Method                        |
|-------|-------------------|-------------------|-------------------------------|
| 1     | D3, Dw (yarn/10cm), D2, D1b |                   | Enter                         |
| 2     | Dw (yarn/10cm) | Backward (criterion: Probability of F-to-remove >= .100) |                               |

a. Dependent Variable: Prwarp (daN)
b. All requested variables entered.

The technological density of weft yarns Dweft (yarns/10cm) has no significant change in tensile strength for the wool fabric type.

\( H_0: \) between the values of the tensile strength of the fabrics there are no significant differences depending on the fiber composition, the tensile strength of the warp yarns \( \text{Pr}_{\text{warp}} \) (N) and technological density of weft yarns \( D_{\text{weft}} \) (yarns/10cm).

\( H_1: \) between the values of the tensile strength of the fabrics there are significant differences depending on the fiber composition, the tensile strength of the warp yarns \( \text{Pr}_{\text{warp}} \) (daN) and technological density of weft yarns \( D_{\text{weft}} \) (yarns/10cm).

3.5. Hypotheses on errors

3.5.1. \( M (\varepsilon) = 0 \) (zero average error). Statistical assumptions about errors in this study can be formulated as follows:

\( H_0: M (\varepsilon) = 0 \)

\( H_1: M (\varepsilon) \neq 0 \)

Verification of these assumptions are made by applying t-test Student for testing the error (Unstandardized Residual), and the results are shown in table 5.

Table 5. Student t-test for testing of errors mean.

|                      | t    | df | Sig. (2-tailed) | (2-Mean Difference) | 95% Confidence Interval of the Difference |
|----------------------|------|----|-----------------|---------------------|-----------------------------------------|
|                      |      |    |                 |                     | Lower | Upper                   |
| Unstandardized Residual | 0,000 | 23 | 1,000           | 0E-8                | -2.886564 | 2.886564               |

From table 5 it can be shown that the value of Sig. = 1 (> 0.05), so Ho is accepted, the average errors is Zero, \( M (\varepsilon) = 0 \).

3.5.2. \( V (\varepsilon) = \sigma^2 \) (homoscedasticity hypothesis). To test this hypothesis a non-parametric test of correlation between the estimated errors and the dependent variables is applied and it is calculated the Spearman correlation coefficient and Student test for this coefficient (Table 6). In statistics, Spearman's rank correlation coefficient is a nonparametric measure of rank correlation (statistical dependence between the ranking of two variables). The Spearman correlation between two variables is equal to the Pearson correlation between the rank values of those two variables; while Pearson's correlation assesses linear relationships, Spearman's correlation assesses monotonic relationships (whether linear or not). If there are no repeated data values, a perfect Spearman correlation of +1 or −1 occurs when each of the variables is a perfect monotone function of the other.
Hypothesis statistics:

**H0**: the correlation coefficient is insignificantly larger than zero (the null hypothesis of the Student t-test is accepted);

**H1**: the correlation coefficient is significantly larger than zero (the null hypothesis of the Student t-test is rejected).

### Table 6. Spearman test to verify the homoscedasticity hypothesis.

|          | D1          | D2          | D3          | Pr\(_{\text{warp}}\) (daN) | D\(_{\text{weft}}\) (yarn/10cm) | Unstandardized Residual |
|----------|-------------|-------------|-------------|-----------------------------|---------------------------------|------------------------|
| **Spearman’s rho** |             |             |             |                             |                                 |                        |
| D1       | Correlation Coefficient | 1.000       | -0.370      | -0.287                      | 0.536**                        | 0.226                  | 0.113                  |
|          | Sig. (2-tailed)        | 0.000       | 0.075       | 0.174                       | 0.007                          | 0.289                  | 0.600                  |
| D2       | Correlation Coefficient | -0.370      | 1.000       | -0.258                      | 0.431*                         | 0.202                  | -0.056                 |
|          | Sig. (2-tailed)        | 0.075       | .           | 0.223                       | 0.036                          | 0.344                  | 0.796                  |
| D3       | Correlation Coefficient | -0.287      | -0.258      | 1.000                       | -0.646**                       | -0.227                 | -0.048                 |
|          | Sig. (2-tailed)        | .174        | 0.223       | .                           | 0.001                          | 0.287                  | 0.822                  |
| P\(_{\text{warp}}\) (daN) | Correlation Coefficient | 0.536**     | 0.431*      | -0.646**                    | 1.000                          | 0.393                  | 0.475**                |
|          | Sig. (2-tailed)        | 0.007       | 0.036       | 0.001                       | .                              | 0.057                  | 0.019                  |
| D\(_{\text{weft}}\) (yarn/10cm) | Correlation Coefficient | 0.226       | 0.202       | -0.227                      | 0.393                          | 1.000                  | 0.152                  |
|          | Sig. (2-tailed)        | 0.289       | 0.344       | 0.287                       | 0.057                          | .                      | 0.477                  |
| Unstandardized Residual | Correlation Coefficient | 0.113       | -0.056      | -0.048                      | 0.475*                         | 0.152                  | 1.000                  |
|          | Sig. (2-tailed)        | 0.600       | 0.796       | 0.822                       | 0.019                          | 0.477                  | .                      |

**.** Correlation is significant at the 0.05 level (2-tailed).

**.** Correlation is significant at the 0.01 level (2-tailed).

Values of Sig. t for D1 correlations - expected errors (0.600) D2 - expected errors (0.796) D3 - expected errors (0.822), D\(_{\text{weft}}\) (yarn/10 cm) - expected errors (0.477), Pr\(_{\text{warp}}\) (daN) - expected errors (0.019) are > 0.05, so the null hypothesis of the Student test is rejected, so the model is homoscedastic.

3.5.3. \( \varepsilon \sim N (0, \sigma^2) \) - normality hypothesis. Testing normality of the distribution of errors is the Kolmogorov-Smirnov non-parametric test (table 7).

### Table 7. Testing normality hypothesis. One-Sample Kolmogorov-Smirnov.

|          | Unstandardized Residual |
|----------|-------------------------|
| N        | 24                      |
| Normal Parameters\(^{a,b}\) | Mean \(0E-7\) Std Deviation 6,8359 Absolute 0,170 |
| Most Extreme Differences | Positive 0,168 Negative -0,170 |
| Kolmogorov-Smirnov Z | 0,832 |
| Asymp. Sig. (2-tailed) | 0,493 |

\(^{a}\) Test distribution is Normal; \(^{b}\) Calculated from data.
Value Sig = 0.493 (more than the value of 0.05), so it supports the hypothesis of normality (Ho)

3.5.4. cov (εi, εj) – testing of errors autocorrelation. Hypothesis statistics:
Ho: \( \rho = 0 \) (errors are not autocorrelated)
H1: \( \rho \neq 0 \) (errors are autocorrelated)
Verification is done with Durbin Watson test (table 8).

| Model | R | R Square | Adjusted R Square | RStd. Error of the Estimate | Durbin-Watson |
|-------|---|----------|--------------------|-----------------------------|---------------|
| 1     | 0.974* | 0.949    | 0.942              | 7,33073                    | 2,168         |

Value of 2.168 is compared to the calculated value of the test (dl, du). It is noted that the value obtained is within the range (du, 4 - du), which leads to the acceptance of the null hypothesis (no autocorrelation of errors).

3.6. Testing collinearity of independent variables

| Model | Unstandardized Coefficients | Standardized Coefficients | Sig. | 95.0% Confidence Interval for B | Collinearity Statistics |
|-------|-----------------------------|---------------------------|-------|-------------------------------|------------------------|
|       | B          | Std. Error  | Beta    |               | Lower Bound | Upper Bound | Tolerance | VIF   |
|       | (Constant) | 29.637      | 9.543   | 3.106          | 0.006       | 9.663      | 49.611       |
| 1     | Dweft      | 0.014       | 0.039   | 0.020          | 0.365       | 0.719      | 0.068       | 0.854 | 1.171 |
|       | D1         | 45.874      | 4.160   | 0.701          | 11.02       | 0.000      | 37.166      | 54.581 | 0.655 | 1.528 |
|       | D2         | 45.522      | 4.337   | 0.663          | 10.49       | 0.000      | 36.445      | 54.599 | 0.664 | 1.507 |
|       | D3         | -25.955     | 4.706   | -0.325         | -5.515      | 0.000      | -35.805     | -16.105 | 0.761 | 1.314 |

The indicator VIF has a high value of between (1.171; 1.528) indicating that there is collinearity between the independent variables used in the model.

4. Conclusions

By applying and interpreting regression model ANCOVA sig value can conclude that there are significant differences between the variance of tensile strength of woven fabrics depending on fiber composition, tensile strength of warp yarns \( P_{\text{warp}} \) (daN), the null hypothesis Ho is rejected.

Technological weft density \( D_{\text{weft}} \) (yarns/10cm) does not significantly influence the tensile strength variation of woollen woven fabrics.

The ANCOVA model permits us to evaluate the homogeneous character of a population by separating and testing of the effects caused by the considered factors.

If the test data obtained after trials on the elements of a sample taken from one homogeneous population are divided in distinct groups, then the mean values of the groups do not differ significantly between themselves.
In the case of a non-homogeneous population, the deviations of the individual values as compared to the mean value are not anymore accidental and when dividing the test data in distinct groups the mean values are different between themselves significantly because of some causes having a systematic action.

ANCOVA model included as independent variables, both dummy or alternative variables (fiber composition) and numerical variables (tensile strength of warp and weft yarn density technology) and as the dependent variable, tensile strength woven fabrics.

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