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STUDY REGARDING THE ASSOCIATION BETWEEN MECHANICAL PARAMETERS, CHEMICAL COMPOSITION AND ERICHSEN INDEX

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Abstract: *The chemical composition, mechanic properties and Erichsen index determined for 74 specimen of thin sheet form temper steel, type A3K02, were examined by multivariate data analysis, using principal component analysis (PCA). The analysis of the principal components sheds light on the correlations between the variables as well as on the differences between the variables analyzed. The values of the correlation coefficients indicate important direct statistical relations between the variables tensile strength (R_m) and content of manganese (Mn), Erichsen index (IE) and indirect correlation between the elongation (A_{80}) and content of manganese (Mn), respectively tensile strength (R_m).*

Key words*: chemical composition, mechanical properties, Erichsen index, principal component analysis*

1. INTRODUCTION

In automobile component materials, it is necessary to use steel sheet with good formability proprieties. Studies on formability utilize tests which can provide sufficient information about the material's proprieties. One method to evaluate the sheet formability is carried out using the results of tensile test. The tensile test is an important procedure used to characterize the mechanical behaviour of materials: tensile strength (R_m), yield strength (R_e), and elongation (A_{80}) (Cabezas & Celentano, 2004). The chemical composition is an important group of factors that affects the tensile behaviour and the microstructure (Kuang et al., 2009; Safaeirad et al., 2008). Another method to determine the formability of the steel sheet uses deep drawing applications is the Erichsen test (García et al., 2008). This test, which consists of the deep drawing of circular sheets using a spherical punch, provides the so-called Erichsen index (IE), obtained as the punch penetration corresponding to the maximum punch force. Alloying elements in the material structure affect its mechanical characteristics and technological properties (Kudrya et al., 2008). The characteristics of thin steel sheets are affected (Panigrahi et al., 2009) not only by their carbon content, but also by the quantity of accompanying elements, elements from raw materials, added from the process or from the environment. In the category of additional elements there are: manganese (Domínguez et al., 2002), (Nam & Lee, 2000), silicon, aluminium, sulphur, phosphorus, oxygen, hydrogen, nitrogen.

2. EXPERIMENTAL RESEARCH

The aim of the research study in this paper is to study the relation between chemical elements contained in the thin steel sheets, mechanic proprieties and Erichsen index.

The composition of the metal sheet was determined by using an spectroscope with atomic emission POLYVAC and contained the following chemical elements: carbon (C), manganese (Mn), silicon (Si), phosphor (P), aluminium (Al).

The tensile tests were made on Tinius-Olsen equipment with the force domain between 3 kN and 150 kN. A strain gauge type Epsilon 3542-050 M-020-ST, B1 class was used. The elongation speed was constant. The engineering strain or elongation is computed as $(L - L_0) = L_0$, with L and L_0 being the current and initial extensometer lengths (Cabezas & Celentano, 2004).

Thin sheets of cold rolled steel for drawing operation were analyzed. The materials of sheets are according to standard SR EN 10130 + A1: 2000. The tensile specimens were extracted from 1.5 mm thick sheets. The axis of the specimen was at 90^o form rolling direction. The samples were taken from different places of a roll of sheet. The research has used a group of 74 data sets. The result was taken into account based on the values obtained from three samples taken from the roll sheet and inserted in the database. The data was centred and normalized. The chemical composition, mechanic proprieties properties and IE for the studied thin steel sheets, the means and range with abbreviated names are given in Tab. 1.

To highlight the relationship between the chemical composition of elements, the mechanical characteristics and IE for steel sheets the Principal Components Analysis (PCA) was applied. Through this multivariate statistical technique, the number of variables was reduced but has preserved as much of the original data variance. The new variables of the principal components (PCs) were determined, expressed as linear combinations of original variables, which have maximum variance. PCs are uncorrelated variables two by two. The first principal component (PC1) has maximum variance and the second principal component (PC2) has a variance as high as possible, but less than that of the PC1.

The correlations between the variables studied are presented in the correlation matrix – a square matrix symmetric towards its main diagonal, which highlights the values of correlation coefficients between variables. The values of Pearson correlation coefficient (r) reflect the degree of linear relationship between two variables.

The multivariate statistical method – PCA was performed with the SPSS software version 16.0; a $p < 0.05$ and was considered statistically significant.

The Bartlett test of sphericity was used to verify the null hypothesis, according to which the correlation matrix is an identity matrix.

Variables	Mean	Range		Std. dev.
		min.	max.	
C [%]	0.043	0.030	0.060	0.009
Mn [%]	0.258	0.200	0.320	0.039
Si [%]	0.015	0.010	0.050	0.0143
S [%]	0.012	0.009	0.018	0.0030
P [%]	0.012	0.006	0.017	0.0033
Al [%]	0.032	0.000	0.054	0.0123
R_e [N/mm^2]	206.25	179.00	235.00	13.246
R_m [N/mm^2]	330.14	312.00	362.00	11.142
A_{80} [mm]	38.78	35.00	42.50	1.877
IE [mm]	12.19	11.50	12.70	0.326

Tab.1. Limits of the variables used in the multivariate analysis

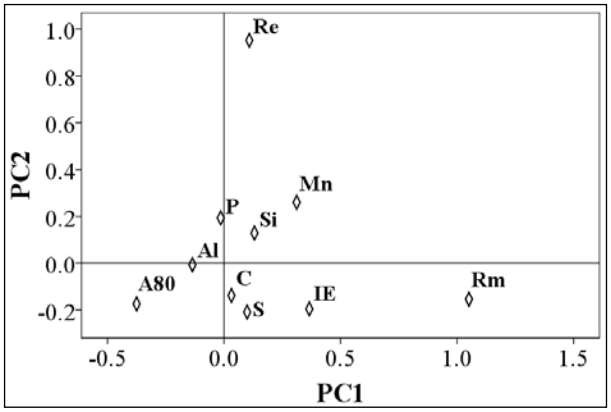

Fig. 1. PC1 and PC2 score for the chemical composition, mechanic proprieties and Erichsen index

The result of this test (170.556, p = 0.000 < 0.05) is significant, the null hypothesis was rejected and the research hypothesis according to which the correlation matrix differs by the identity matrix was accepted. The correlations between variables (over 0.30) and the result of Bartlett test shows that the multivariate technique – PCA is indicated.

The adequacy check of all PCA variables of the sample was conducted with the Kaiser – Meyer – Olkim (KMO) test. The values obtained for KMO (0.647) justify the application of the PCA technique as specified by (Field, 2002).

The selection criterion of number for PCs was the one proposed by Kaiser and retained the PCs that have eigenvalue $\lambda > 1$, because it provides more information than the original variables. At the same time, the criterion recommended by Stevens (1996) has been taken into account, according to whom the PCs extracted explain at least 70% of the total variance of original variables.

The correlations between the results obtained for the chemical composition, mechanic proprieties and IE are represented in Figure 1. Bi-plots show the position of explanatory variables and identify how the variables relate to both PCs and other input.

The first two PCs explain 99.06% of the total variance (PC1 = 68.95% and PC2 = 30.11%). Along the PC1 axis, the parameters R_m and IE are well correlated and are indirectly correlated with A_{80}. The PC2 opposes the parameter R_e to A_{80}. In regard to PC2, the parameter A_{80} is placed in the left of the graph which show that this contributes to a larger extent to the evaluation of deformability of the steel sheets in comparison with the variables in the right.

The Mn is positioned in both plots at the same distance, a fact that indicates a similar correlation both between the R_m and R_e parameters. The content of Mn is directly correlated with R_e (r = 0.409), R_m (r = 0.375) and indirectly correlated with A_{80} (r = – 0.408), at a significant level of p = 0.01. The increase of Mn will increase R_e, R_m and will decrease the A_{80} with effect on decreasing the steel sheets deformability. Additions of Mn in range of 0.25 to 0.30 weight % increase the mechanical properties since coarse precipitates are avoided; the microstructure forming Al-Mn precipitates and a fine lamellar microstructure (Domínguez et al., 2002) and forms a manganese dispersoid of Al_6Mn (Nam & Lee, 2000).

The closeness of the chemical elements Al, P, Si, C and S to the centre of de PCs shows that these variables have a reduced contribution to describe the deformability of the thin sheet analyzed.

From the point of view of the IE, there is a correlation (r = 0.311) between the index and the R_m, at a significant level of p = 0.01. The dependence of the R_m and the IE indicates a medium effect between the two parameters. The increase of the R_m leads to an increase of the IE, respectively the deformability of the thin sheet.

The A_{80} is indirectly correlated with R_e (r = - 0.351) and R_m (r = - 0.409), significant correlations at p = 0.01.

Significant correlations at p = 0.01 were obtained among some elements of the chemical composition; between C and P (r = - 0.538), Al (r = - 0.338); between Mn and Si (r = 0.436), P (r = - 0.320), Al (r = - 0.321); between Si and S (r = - 0.309), Al (r = - 0.422); between P and Al (r = 0.380).

3. CONCLUSIONS

The PCA of the data set shows a strong association between mechanical parameters R_e, R_m, A_{80}, chemical element Mn and Erichsen index IE.

Regarding the correlation between the mechanical parameters and IE, a direct correlation between R_m was obtained for the steel sheets studied and IE. A significant indirect correlation was obtained between R_m and A_{80}.

The Mn content directly affects the mechanical parameters R_e şi R_m and indirectly A_{80}. Significant correlations were obtained between some elements of chemical composition.

This study allows, for a new research direction, to establish a predictive model using multiple regression analyses. It can get prediction models of the connections which are established between the components of the micro alloying structure and mechanical properties and deformation capacity for the steel sheets.

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