ANALYSIS OF SELECTED PROPERTIES OF STEEL USED FOR TOOLS FORMING A BAND ASSIGNED FOR THE PRODUCTION OF CERAMIC ROOFING TILES IN THE ASPECT OF METHODS OF PROLONGING THE PERFORMCANCE LIFE

[1]Jan MARZEC, [1]Marek HAWRYLUK, [1]Tadeusz LEŚNIEWSKI, [1]Marzena LACHOWICZ, [1]Anna KUŚ, [2]Magdalena JABŁOŃSKA

[1]Wroclaw University of Science and Technology, Wroclaw, Poland, EU *jan.marzec@pwr.edu.pl, marek.hawryluk@pwr.edu.pl, tadeusz.lesniewski@pwr.edu.pl, marzena.lachowicz@pwr.edu.pl, anna.kus@pwr.edu.pl*

[2]Silesian University of Technology, Gliwice, Poland, EU *magdalena.jablonska@polsl.pl*

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Abstract

The article presents results of a complex wear analysis of forming tools in the process of band extrusion for ceramic roofing tiles. The materials for such tools must be especially resistant to abrasive wear, which occurs because of contact with the extruded ceramic mass band, which consists mostly of clay (70 %), quartz sand (10 %) and flour from ceramics recycling (20 %). Investigated material was tool steel NC11LV characterized in different hardness levels, collected directly from the forming tools. Tests included an analysis of the abrasion resistance conducted with the use of a dry abradant, tests of the microstructure and topography of the worn surface, as well as nanohardness and Young modulus measurements using a nano indenter. The whole can be confronted with the results of performance tests carried out so far, during which the tools working on the production lines were subjected to 3D scanning.

The obtained results confirm better abrasive wear resistance parameters, with respect to forming tools, is demonstrated by steel NC11LV with a higher hardness, which is illustrated by the relative wear resistance index K_b obtained during the dry abradant tests, which, for NC11LV with a lower hardness, equals 1,548, and for the hardened steel with a higher hardness, it is 1,810. NC11LV owes good properties mostly to the hard carbide precipitates. Higher niobium content results in niobium carbides in the microstructure and in this way to a higher hardness of material. Other possibilities of prolonging the life of forming tools represents e.g. the nitriding.

Keywords: abrasive wear resistance, ceramic roof tile, tool steel, microstructure

1. INTRODUCTION

Presently, one of the main aspects in the development of the ceramic industry is optimization of materials used for machine elements in respect of durability increase. This relates to the demanding working environment and the continuously growing production efficiency. The performed tests determined the most important parameters of tool steels used for tools forming ceramic roofing tiles in the process of extrusion.

Machine elements in this process are especially exposed to abrasive wear, which occurs as a result of contact with the processed ceramic mass, which consists mainly of clay (70 %), quartz sand (10 %) and flour from ceramics recycling (20 %) [1, 2]. Intensive abrasive wear is mostly caused by the hard fractions in the treated mass, which play the role of an abradant and lead to tool degradation. The loose movement of the abradant particles can lead to scratching, micromachining or plastic deformation (ridging) of the tool material. The most intensive abrasion takes place in the process of band extrusion, where the production mass is mixed, homogenized, vented and shaped [3]. Elements especially exposed to abrasion are the tools forming the band (bits).

In order to ensure an appropriately long performance time of the forming tools, abrasion resistant materials are used, which include mostly: wear resistant Hardox steels and cold work tool steels [4]. An especially good alternative is constituted by steel NC11LV (X153CrMoV12) subjected to an additional thermal treatment. These steels owe their good abrasion resistance parameters to their high chromium content (10-15 %) and alloy additions in the form of molybdenum and vanadium (about 1 %) [5, 6]. An additional thermal treatment leads to the formation of carbides, mainly M_7C_3, in the microstructure, whose size, shape and distribution significantly affect the hardness, which translates to a limited abrasive wear [7, 8].

The scientific problem undertaken in this article is an experimental analysis of the abrasion resistance and selected properties of hardened steel NC11LV in the aspect of its use for forming tools in the process of band extrusion for ceramic roofing tiles.

2. DESCRIPTION OF THE PROCESS AND THE TOOLS IN BAND EXTRUSION FOR CERAMIC ROOFING TILES

Within the performed studies, tool steel NC11LV used for forming tools in the production of ceramic roofing tiles was verified. The basic task of these tools is providing the shape and thickness to the band, which, at the following stage, is cut into a specific dimension and then transported to a punch press, where the final shape of the tile is formed. The forming tools, as shown in **Figure 1**, are mounted at the end of a pug mill, which, depending on the capacity, extrudes the mass under the pressure of 2 – 10 MPa, the effect of which are high pressures operating on the tool, which lead to intensive abrasive wear [9, 10].

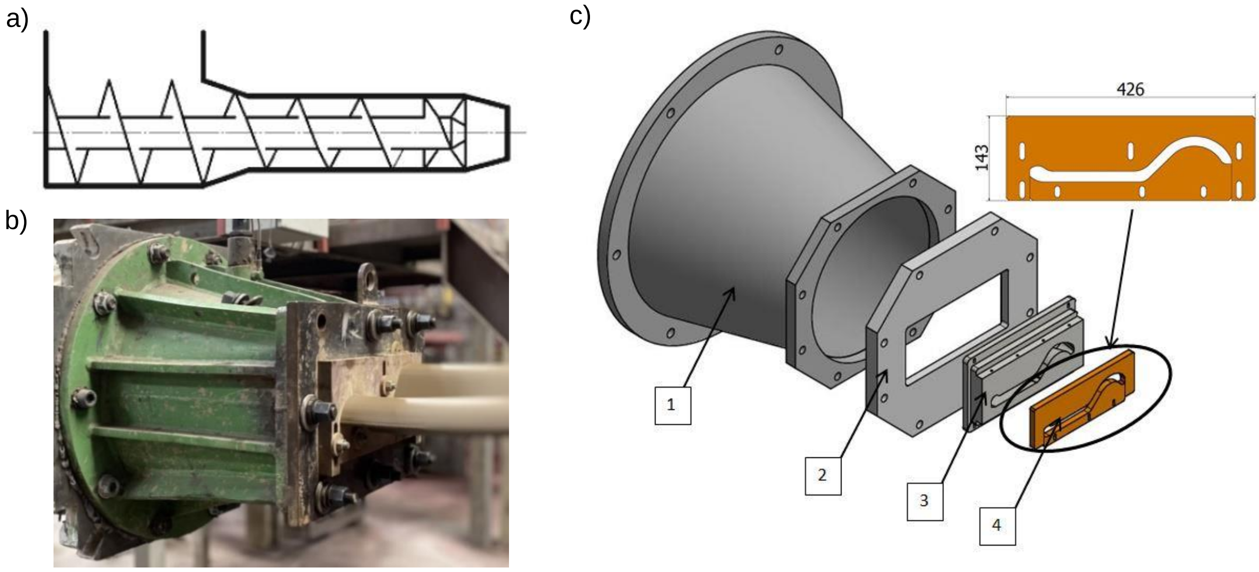

Figure 1 Process of forming a band a) an extruder scheme [9], b) forming tools during operation, c) a scheme of the tool set forming the band for ceramic roofing tiles: 1 – a conical head, 2 – a mounting plate, 3 – an extrusion die, 4 – a forming tool

A special attention should be paid to these tools because the degree and type of their wear affect the quality of the final product. The geometry of the bit differs depending on the produced assortment.

3. METHODOLOGY AND TEST DESCRIPTION

Within the performed investigations of the properties of the forming tool materials, cold work tool steel NC11LV (X153CrMoV12) was verified. The examined samples characterized in the chemical composition presented in **Table 1**.

|**Table 1** Chemical composition of tool steel NC11LV test samples

	C	Si	Mn	P	S	Cr	Mo	Ni	V	W	Cu	Nb
NC11LV/1	1.49	0.40	0.24	0.023	0.006	11.43	0.73	0.22	0.75	0.13	0.09	0.06
NC11LV/2	1.56	0.38	0.21	0.028	0.008	11.81	0.74	0.19	0.77	0.17	0.12	0.20

The examined samples of steel NC11LV were collected from the tools which had worked over a production cycle and characterized in different degrees of wear.

At the first stage of the conducted tests, in order to verify the selected properties of the NC11LV steel samples, the hardness and the Young modulus were determined. The tests were caried out by the instrumented indentation testing method (IIT) with the use of an Anton Paar, NHT3 nano indenter on the Step 4 platform. The method makes it possible to determine the desired parameters during one precise and fast measurement.

The analysed materials were also subjected to abrasion resistance tests on a testing station Tester T-07 produced by MCNEMiT in Radom, shown in **Figure 2**. The test is conducted by means of a loose dry abradant, which is applied in between the samples, and a disk rotating at a preset rotational speed (1800obr/min) for 30 minutes. The parameter determining the abrasion resistance in this test is coefficient Kb, which, in turn, is determined based on the formula:

$$K_b = \frac{Z_{ww} \cdot \rho_b \cdot N_b}{Z_{wb} \cdot \rho_w \cdot N_w} \tag{1}$$

where:

Z_{ww} – weight wear of the quartz sample (g)

Z_{wb} – weight wear of the examined material (g)

ρ_w – density of the model material

ρ_b – density of the examined material

N_w – number of turns of the friction path of the model sample,

N_b – number of turns of the friction path of the examined sample.

Figure 2 Testing station for a dry abradant test T-07

The abradant applied in these tests was elektroloxite no. 90, and the model sample was made of steel C45 in a normalized state with the hardness of about 200 HB.

4. RESULTS OF MEASUREMENTS OF SELECTED PROPERTIES

In order to further verify the properties of the examined materials, measurements were made by means of a nano indenter (Anton Paar, NHT3 on the Step 4 platform), in which the hardness and the Young modulus were determined. The measurements were performed for different distances from the sample edges to see how these parameters change deeper into the material. **Figure 3** compiles the measurement results for the hardness and the elastic modulus for both materials in the form of diagrams.

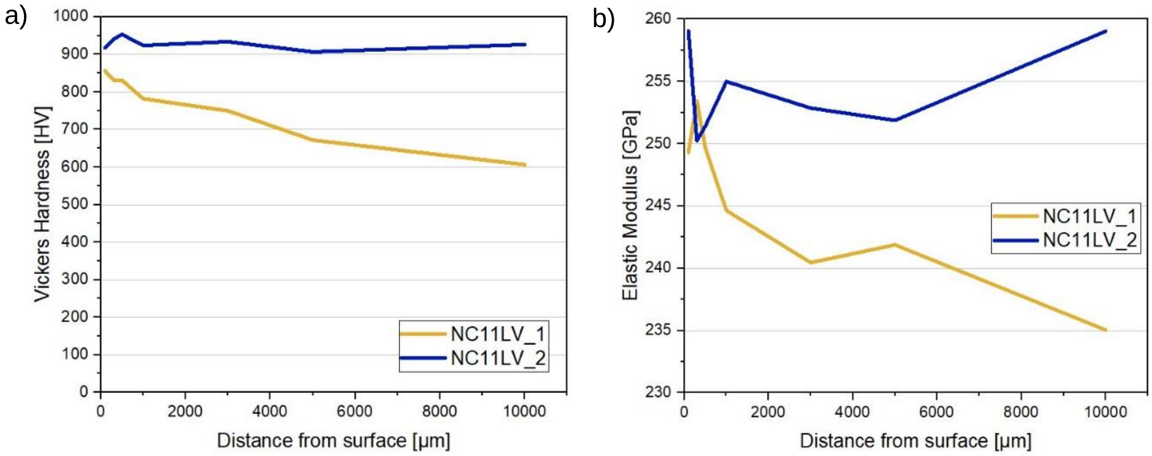

Figure 3 Results of a test by means of a nanoindenter a) hardness, b) Young modulus

The analysis of the obtained comparative results shows that sample NC11LV/2 characterized in a higher hardness equalling, at the examined depth, about 920-950HV. On sample NC11LV/1, with the increasing depth, we can also see a drop of hardness, which initially equals over 830HV and at the end of the measurement, it drops to the level of 600HV. In the measurements conducted with the use of the nano indenter, the indentation modulus (EIT) was also determined, which is comparable with the Young modulus. For the harder sample NC11LV/2, the value of this modulus was within the scope of 250-260 GPa, and for sample NC11LV/1, with a lower hardness, it oscillated between 235 and 250 GPa. And so, a higher E as well as a higher hardness predestine NC11LV/2 for the target material to be used for tools applied in the band extrusion process.

5. RESULTS OF A DRY ABRADANT TEST AND A MICORSTRUCTURE ANALYSIS

An abrasion resistance test with the use of a dry abradant was carried out on a T-07 tester, on two samples made from NC11LV with different hardness values. After a specific time of the dry abradant operating on the examined materials, a measurement of the weight loss was made. Based on the obtained weight wear results, the relative abrasion wear resistance was calculated K_b, referred to the model material (steel C45). The results of the dry abradant tests have been presented in **Table 2** and illustrated in diagrams in **Figure 4**.

Table 2 Results of a dry abradant test for the examined materials

Sample no.	Average hardness HV	Rotational speed [obr/min]	Weight wear – average value [g]	Relative abrasion wear resistance Kb
NC11LV/1	760	1800	0.12	1.550
NC11LV/2	930	1800	0.10	1.860
C45 (model)	240	600	0.062	1.000

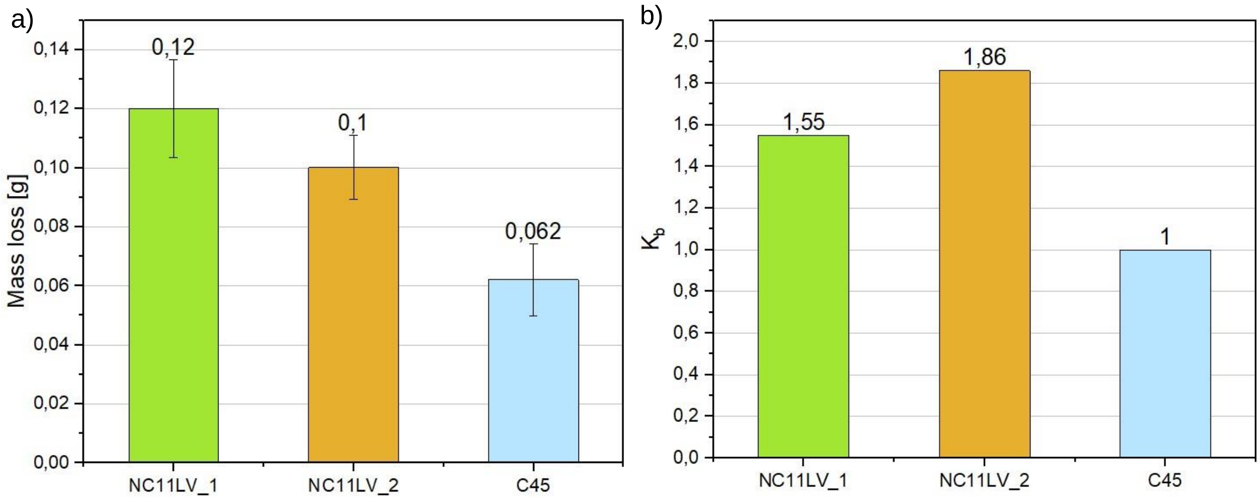

Figure 4 Comparison of the dry abradant test results a) weight wear – average value [g] b) relative abrasion wear resistance Kb

While analysing the abrasion wear resistance results obtained by means of a T-07 tester, we can notice that a better relative abrasion resistance parameter is exhibited by the harder sample. This parameter, for steel NC11LV hardened to 930HV, equalled 1.860, with the value of 1.550 for the sample with the average hardness of 760HV. The obtained results prove that the abrasion resistance depends on the material's hardness. Hardness can serve as the basic criterion for the selection of materials for elements exposed to intensive abrasive wear. However, to have a full picture of the wear mechanisms, we would also have to analyse the process in which the material is to be used as well as the character of the occurring loads.

The performed microscopic tests of the friction face showed that the dominating wear mechanism for both samples was micromachining and scratching of the surface (**Figure 5a, b**). No plastic deformation was observed, which relates to the hardness of the examined materials. The tests performed on the cross-section demonstrated that the materials underwent uniform abrasion. The microstructure of both materials contains chromium and vanadium carbides, arranged in bands. No significant effect of the heterogeneity of the microstructure on the wear mechanism was observed. At the same time, in the material with a higher hardness, niobium carbide precipitates were recorded, which were the cause of the increased hardness of the analysed material (**Figure 5c, d**).

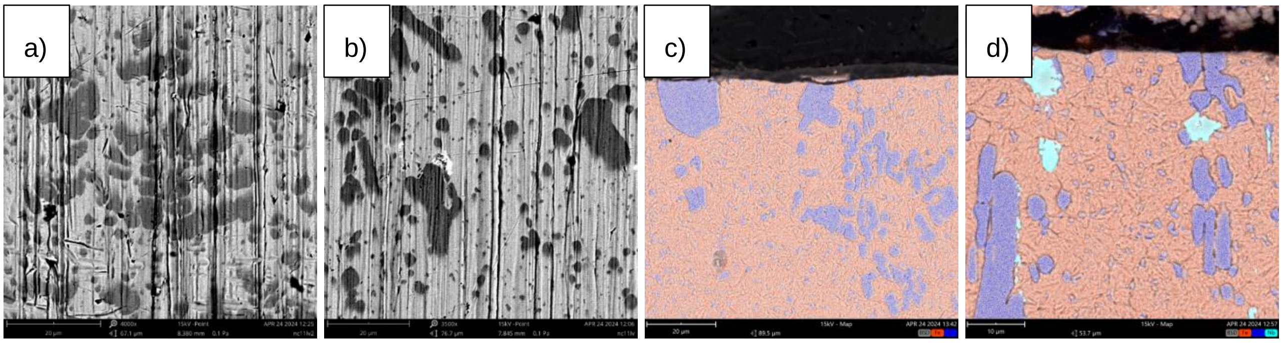

Figure 5 Friction face of the tested materials a) steel NC11LV/1, b) steel NC11LV/2, c) steel NC11LV/1 – cross-section with the plotted distribution of iron, chromium and niobium obtained by the EDX method, d) NC11LV/2 – cross-section with the plotted distribution of iron, chromium and niobium obtained with the use of the EDX and SEM method

The presence of carbides in the microstructure results in a hardness increase, which translates to an improvement of the abrasion resistance determined by parameter K_b.

6. CONCLUSIONS

The article discusses the results of an analysis of tool steel NC11LV used for tools which form a band in the process of ceramic roofing tile production. The verified selected properties of the examined samples of steel NC11LV demonstrated that the main difference is the hardness equalling the average of 760HV for one material, while for the other 930HV. The hardness diversification related to the niobium content in the material, which, in the case of the harder steel, resulted in the presence, apart from the chromium and vanadium carbides, also of niobium carbides in the microstructure. Based on the results of the abrasion resistance tests, it was confirmed that there is a relation between the hardness of steel NC11LV and its resistance to abrasive wear. This means that, in the case of tools forming a band, it is important to properly select the chemical composition. Tests realized at a different stage also showed the significance of the selection of the thermal treatment parameters. The performed studies also demonstrate that the abrasion resistance test carried out by the dry abradant method (T-07) is reliable and well illustrates the wear mechanisms occurring under the industrial conditions of plastic forming of ceramic roofing tiles. The directions of further investigations aiming at optimization of the forming tools made of steel NC11LV will include verification of the possibilities of applying a thermo-chemical treatment (nitriding).

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