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Performance of boron nitride coated tools and dies

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A B S T R A C T

Boron nitride (BN) has been utilized as a significant coating material for cutting tool applications due to its excellent mechanical and chemical properties. Cutting tools, molds and machine parts are coated with BN with the coating system using a sputtering technology – a physical vapour deposition (PVD) process. Design and manufacture of the equipment is made locally. Physical, mechanical and tribological properties such as thickness, friction coefficient, wear, and adhesion are measured by using calotest, tribometer, profilometer, micro and macro scratch test, and nanohardness devices. The results of characterization of the coatings show that wear resistance and hardness increase and BN coatings provide increased efficiency by creating a value-added manufacturing. In this case, the use of BN-coated tools in machining is expected to be one of the best solutions.

A R T I C L E I N F O

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1. Introduction

In recent years, the different coatings are used in order to increase the performance of cutting tools in machining. In this case, Boron Nitride (BN) coating is one of the best solutions for increasing the efficiency of cutting tools. Turkey has the largest boron reserves in the world. The purpose of the BN coating is to use this opportunity and create a wide application area in industry by using environmentally friendly methods [1]. Increasing the efficiency of machining and material cutting speeds, cutting without or minimum coolant and reduction of costs are among the objectives. In line with the increasing demand, there is a cutting tool need which has to resist high temperatures, preserving a cutting edge for a longer time with reduced wear. Boron Nitride (BN) coating technology is developed to supply this need [2]. Boron nitride is mostly found in two polymorphs in the coatings; hexagonal boron nitride (h-BN) and cubic boron nitride (c-BN). Hexagonal boron nitride is well-known as a soft material with low friction coefficient used for lubricating at both low and high temperatures. It is an electrically insulating and thermally conductive material. It has wide applications as a solid lubricant in metal forming dies and metal forming processes at high temperatures [3]. In contrast to hexagonal phase, cubic phase exhibits high hardness and wear resistance which promotes c-BN as a suitable coating material for cutting tools [4]. Owing to these properties, use of cubic boron nitride in cutting tool applications such as dry cutting, high speed machining and cutting of hard materials, is increased within the last years [5].

Sintered cubic boron nitride cutting tools have already been used extensively in the market today. Major drawbacks of sintered c-BN cutting tools are their high cost, poor ductility, and difficulty of forming them into various cutting tool shapes [6]. Its high hardness, low friction coefficient, good thermal conductivity, high electrical resistivity, high wear resistance, and chemical inertness at high temperatures can be stated as some of the outstanding properties of cubic boron nitride. Furthermore, it is also superior to diamond due to its chemical stability against oxygen and ferrous materials at high temperatures [7].

Today, because of the superb features of this coating, it may have a very wide field of study. Among the coating methods, sputtering technique − a physical vapour deposition (PVD) process − comes into prominence because of lower coating temperature. Possibility to deposit thinner coatings and sharp edges and complex forms, PVD magnetron sputtering technique is extensively used for the deposition of boron nitride films in cubic form in many studies [8]. Lower adhesion and extreme compressive stresses in the films are main problems in PVD sputtered coatings but in the current study film thickness of BN is approximately 1 μm so this problem is not observed [9].

BN coating technology is formerly described [10]. It is applied to cutting tools and dies/molds and an up to quadrupled increased lifetime is observed [11]. Studies on hard turning and micro-milling of titanium alloys are conducted by using uncoated and multilayer coated inserts and tools. BN coated tools showed a distinct advantage [12].

The characterizations of coatings are performed by Fourier transform infrared spectroscopy (FTIR), X-Ray photoelectron spectroscopy (XPS) and Scanning Electron Microscopy (SEM) techniques. Mechanical properties of boron nitride coatings on steel substrates are determined by thickness, friction coefficient and wear measurements. In addition, physical, mechanical and tribological properties such as thickness, friction coefficient, wear and adhesion are measured by using calotest, tribometer, profilometer, micro/macro scratch test and nanohardness devices.

2. Experimental

Among the coating methods, sputtering technique − a physical vapour deposition (PVD) process − comes into prominence because of lower coating temperature, possibility to deposit thinner coatings and possibility to deposit sharp edges and complex forms. The lower coating temperature points to the lower energy usage. Using less energy is very important for environment. Cutting tools, molds and machine parts are coated with BN using a coating system where the technology, design and manufacturing is made locally. In the design and production of this system, environmentally friendly methods are used. The photograph of the system is presented in Fig. 1.

Before the coating process, holders are designed to hold the parts to be coated in the vacuum chamber. Designs of holders are carried out according to shapes of coated materials. Designs should be considered to ensure a homogeneous coating. To obtain a clean and a good film, the system is cleaned in detail and general maintenance is carried out. After manufacturing the holders and polishing the samples, they are cleaned by ultrasonic cleaning using nanocleans and chemicals. In some cases, holders are pre-coated. After cleaning, substrates are attached to a substrate holder connected to a spindle mechanism which can be biased by a second RF power supply. Substrates can make either rotary or planetary motion. Also, the rotation speed and direction can be controlled. According to geometry of substrates, substrate can be rotated or kept still. Turning speed is approximately 25-30 rev/min.

Fig. 1 Boron nitride coating system

Fig. 2 Before coating (left) and after coating (right)

The coating is carried out with sputtering technique under high vacuum. A rectangular-shaped sintered h-BN target of dimensions 100 mm × 250 mm is employed as a cathode. After substrates are attached to a substrate holder connected to a spindle mechanism, the vacuum chamber is evacuated to a base pressure lower than 2.66 Pa using a mechanical pump. At this time, hot water is circulated around the system for the evaporation of water molecules in the environment. When vacuum reaches 0.4 Pa, the turbo molecular pump is started. After the vacuum chamber is evacuated to 0.0026 Pa, system is filled with Ar gas and plasma cleaning is performed with 250 W RF for approximately 10 min. Then, system is filled with N_2 gas. The ratio of gases is 5 to 1. The flow rate of the working gases is adjusted by controllers installed on the system panel.

During the deposition, magnetron power applied to the target plate is increased up to 700 W RF gradually and maintained at that value till the end of deposition. Heater temperature is measured by a thermocouple which is attached to heaters. Heater temperature is varied between 200-250 °C for different bias voltage values ranging from 50-200 V.

Throughout the experiment, water circulates through the system. Closed-loop chiller is used to use less water. The growth of the films continues for 3 h for every experiment. Whole procedure continues approximately 5 h. The photographs of some coated parts are presented in Fig. 2 and 3.

Before and after coating, the analyses and evaluations are made by the following devices:

- Calotest,
- Micro/macro scratch tester,
- Nanoindentation tester (NHT),
- Standard tribometer,
- Contact angle,
- Atomic force microscope (AFM),
- Scanning electron microscope (SEM),
- X-ray diffraction (XRD).

Fig. 3 Samples of coated parts-cutting tools & dies

3. Analysis and evaluations

3.1 Thickness measurements

The thickness of BN films is measured by a Calotest device. The thickness of coating is measured in specific range of time and motor speed with abrasive diamond paste. The diameters of balls are 30 mm, 25.4 mm, 20 mm, 15 mm, and 10 mm. The measurements are done with 30 mm diameter ball and 2000 rpm motor speed during 25 min. The results are calculated by Revetest devices. The thickness of BN coating is in the range of 0.7-1 μm after 3 h deposition. The photographs of the Calotest results are presented in Fig. 4 showing the layers after the wear of the coating by the instrument.

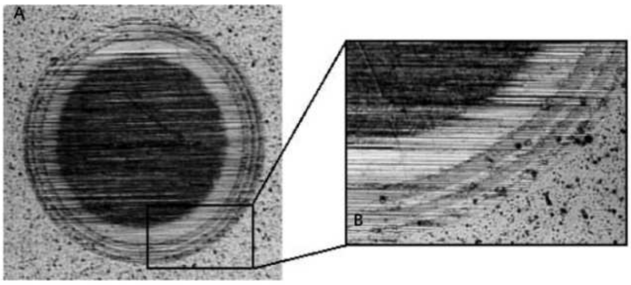

Fig. 4 Results of Calotest

3.2 Adhesion measurements

The quality of adhesion of BN films is measured by micro/macro scratch devices. Loading is started from 0.5 N and progressively increased to 150 N. Rockwell diamond indenter type with a radius of 200 μm is used. 3 mm scratch is formed while indenter is moving at a speed of 6 mm/min. Loading rate is 299 N/min. As shown in Fig. 5, adhesion measurement is investigated by BN and TiN coated steel samples. The results showed that BN coating is better than TiN coating for surface adhesion since delamination is observed with the TiN coating.

Before and after coating, surface of samples are scanned by using AFM and confocal microscope. As shown in Fig. 6, 7, 8 and 9 after BN coating, the sample surface becomes more uniform.

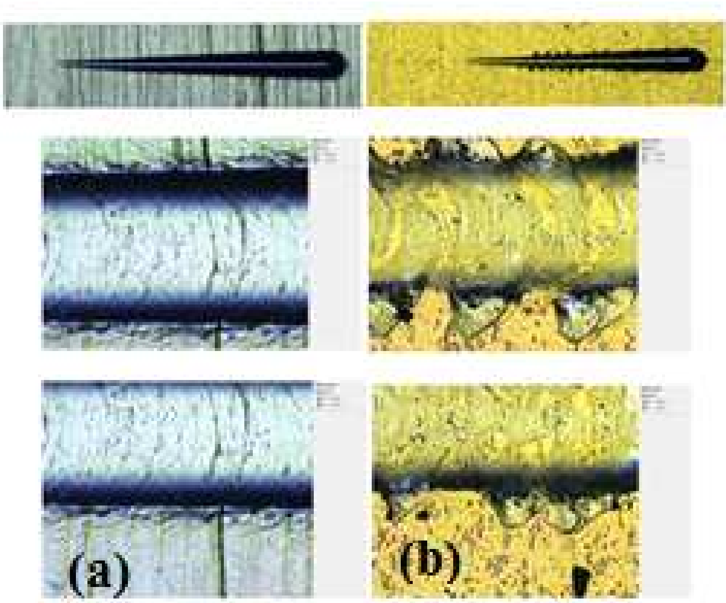

Fig. 5 BN (a) and TiN (b) coated steel sample for surface adhesion

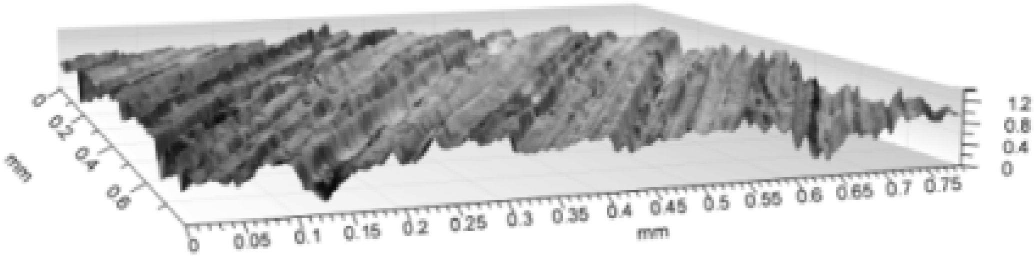

Fig. 6 Uncoated specimen – confocal microscope

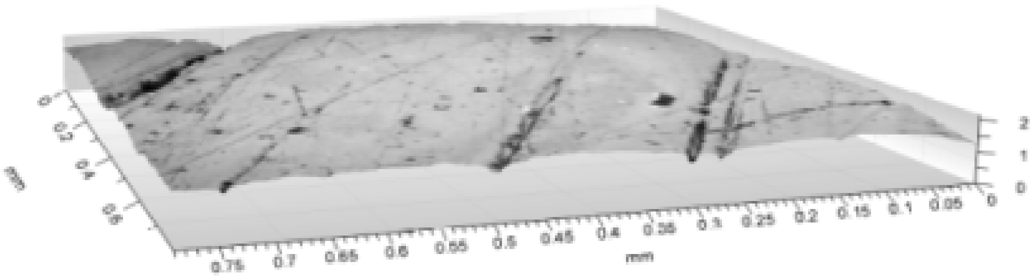

Fig. 7 BN Coated specimen – confocal microscope

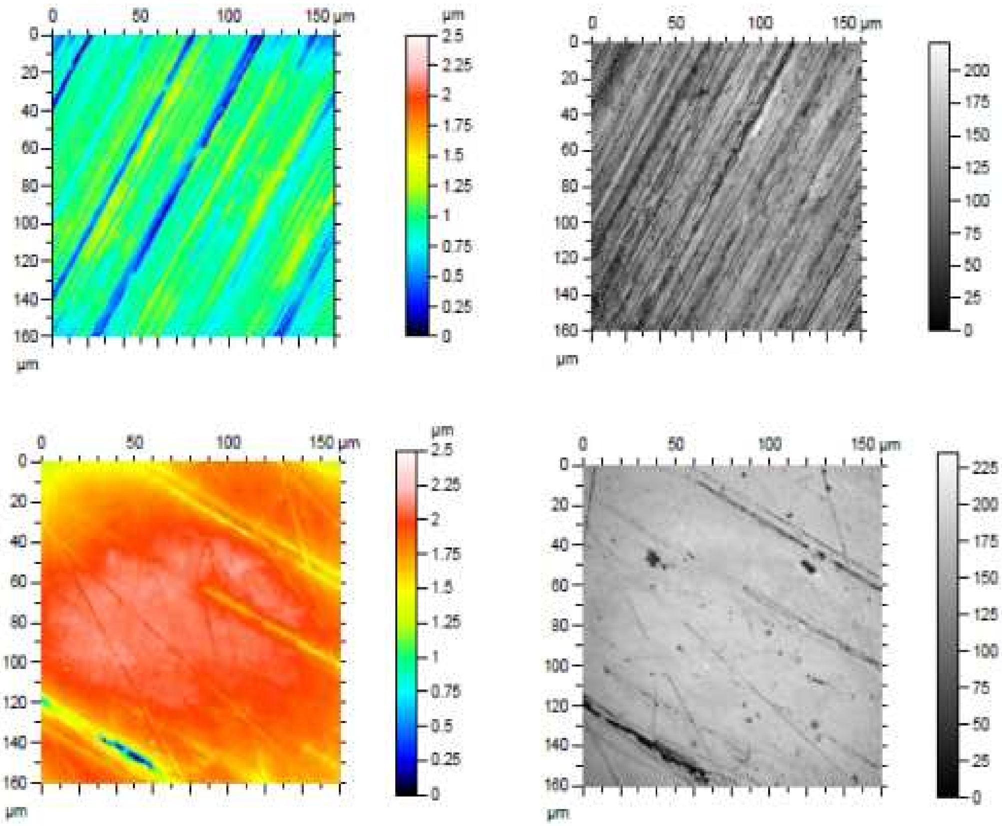

Fig. 8 Surface roughness before and after coating – confocal microscope

As shown in Fig. 10 and 11, the hardness measurements are made with the nanohardness testing device.

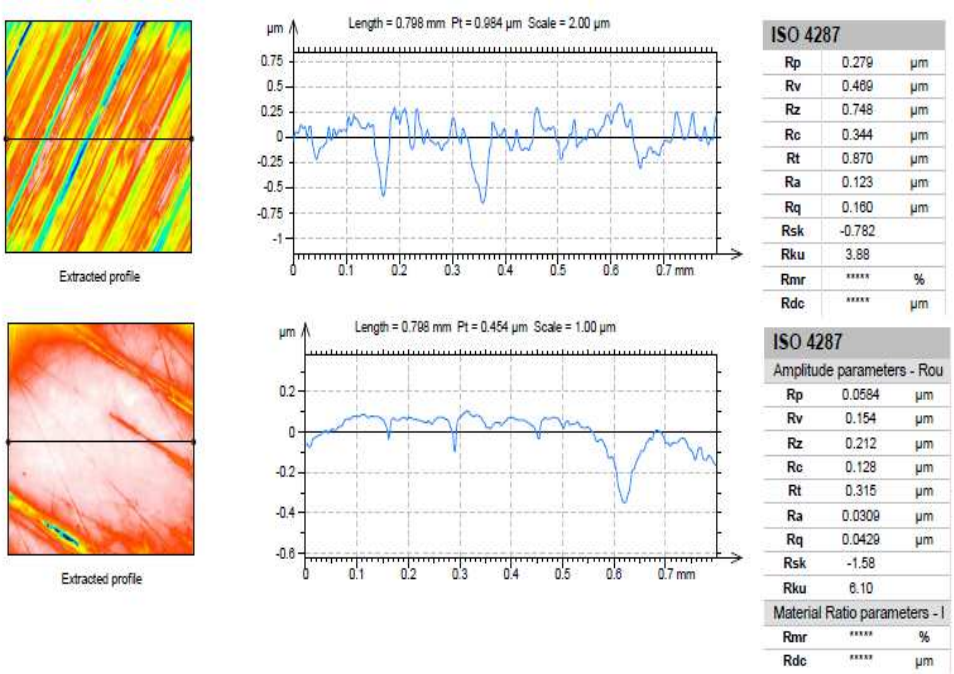

Fig. 9 Surface roughness before and after coating – confocal microscope

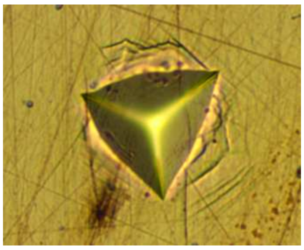

Fig. 10 Nanohardness impression on sample

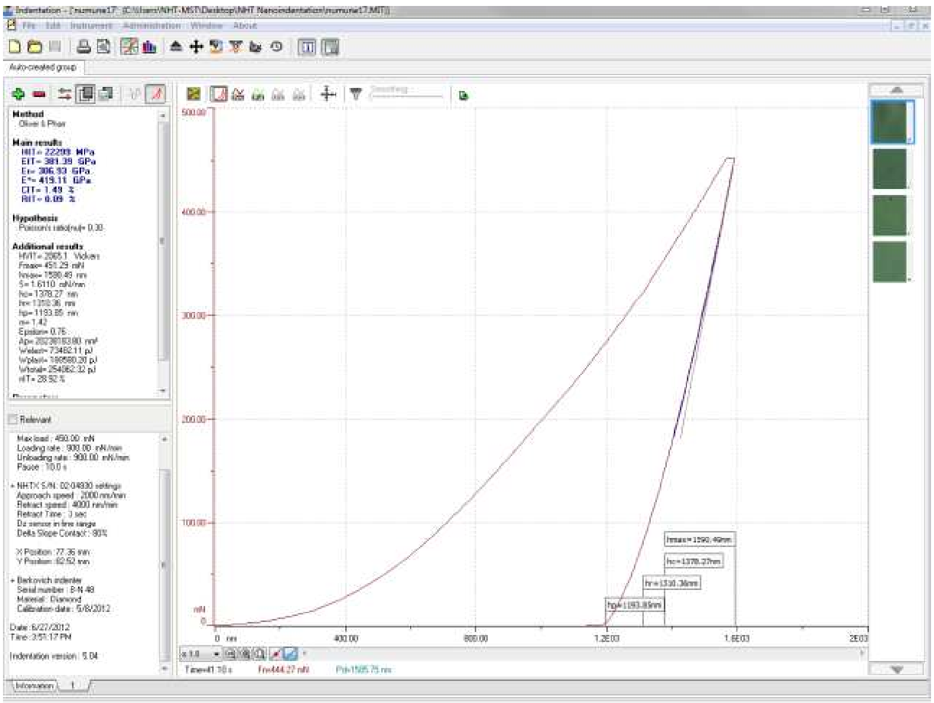

Fig. 11 Nanohardness measurement

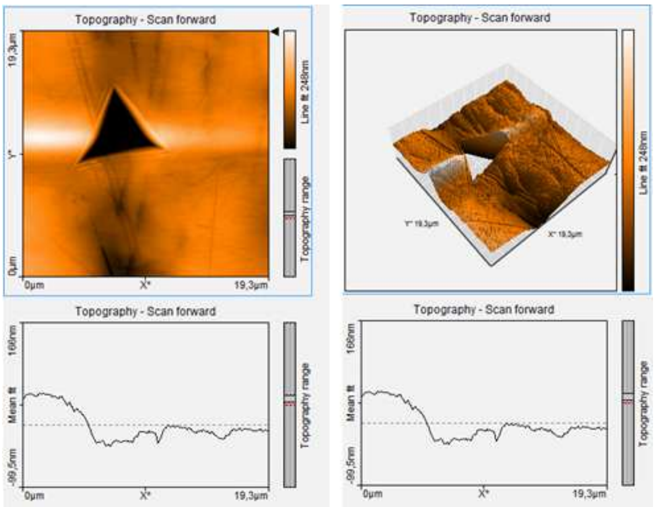

Fig. 12 The AFM images after nanohardness

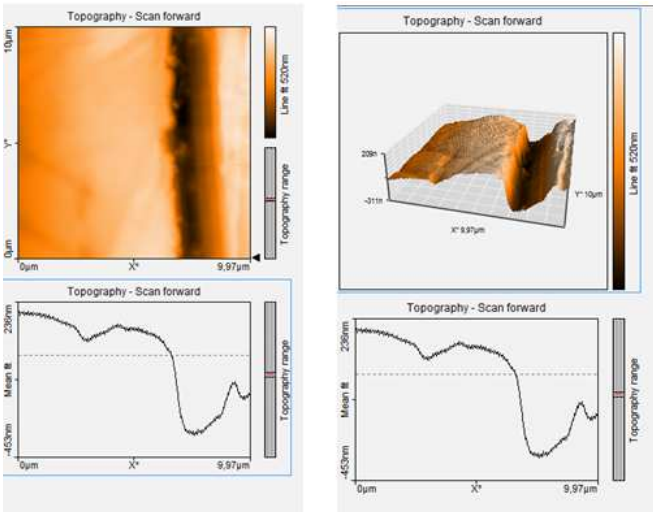

Fig. 13 The AFM images after scratch tests

It is observed that the hardness of samples increase after coating. Later, 3 dimensional surface scan is carried out. The images of the 3 dimensional surfaces are presented in Fig. 12 and 13.

The scratch of sample is scanned in 3 dimensions by using AFM. 3 dimensional images are taken as shown in Fig. 8. Coating adhesion quality and lack of cracks are examined by AFM surface scan. With BN coating, satisfactory results are obtained and no delamination is observed.

4. Conclusion

The results of investigations and the characterization of coated samples showed that boron nitride coating is obtained successfully. The thickness of coating is measured approximately 0.8-1 µm after 3 h deposition. As a result of scratch tests, sufficient adhesion is achieved. The positive effect of BN coating is examined with confocal microscopy in 3 dimensions. By using AFM, the results of nanohardness and scratch test are scanned 3 dimensionally. The 3 dimensional surface images demonstrate that coating can endure high forces and the cracks do not occur. Also, the results of characterization of the coatings show that hardness increases.

The applications of BN coatings in different industrial processes are continuing. They can be used in the coating of cutting tools and dies to increase their life and performance. The increased life is around four times. Cost can be justified if the numbers of coated tools are high.

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References

[1] Pouch, J.J., Alterovitz, S.A. (1990). *Synthesis and properties of boron nitride*, Vol. 54-55, Trans Tech Publications.

[2] Kimura, Y., Wakabayashi, T., Okada, K., Wada, T., Nishikawa, H. (1999). Boron nitride as a lubricant additive, *Wear,* Vol. 232, No. 2, 199-206.

[3] Klages, C.-P., Fryda, M., Matthée, T., Schäfer, L., Dimigen, H. (1998). Diamond coatings and cBN coatings for tools, *International Journal of Refractory Metals & Hard Materials,* Vol. 16, No. 3, 171-176.

[4] Neo, K.S., Rahman, M., Li, X.P., Khoo, H.H., Sawa, M., Maeda, Y. (2003). Performance evaluation of pure CBN tools for machining of steel, *Journal of Materials Processing Technology,* Vol. 140, No. 1-2, 326-331.

[5] Jin, M., Watanabe, S., Miyake, S., Murakawa, M. (2000). Trial fabrication and cutting performance of c-BN-coated taps, *Surface and Coatings Technology,* Vol. 133-134, 443-447.

[6] Zhou, Z.F., Bello, I., Kremnican, V., Fung, M.K., Lai, K.H., Li, K.Y., Lee, C.S., Lee, S.T. (2000). Formation of cubic boron nitride films on nickel substrates, *Thin Solid Films*, Vol. 368, No. 2, 292-296.

[7] Will, G., Perkins, P.G. (2001). Is there a new form of boron nitride with extreme hardness?, *Diamond and Related Materials*, Vol. 10, No. 1, 2010-2017.

[8] Deng, J., Wang, B., Tan, L., Yan, H., Chen, G. (2000). The growth of cubic boron nitride films by RF reactive sputter, *Thin Solid Films*, Vol. 368, No. 2, 312-314.

[9] Bewilogua, K., Keunecke, M., Weigel, K., Wiemann, E. (2004). Growth and characterization of thick cBN coatings on silicon and tool substrates, *Thin Solid Films*, Vol. 469-470, 86-91.

[10] Hu, C., Kotake, S., Suzuki, Y., Senoo, M. (2000). Boron nitride thin films synthesized by reactive sputtering, *Vacuum*, Vol. 59, No. 2-3, 748-754.

[11] Cesur, H., Kaftanoğlu, B., Özel, T. (2009). Machining performance of CBN coated cutting tools for die/mold applications, In: *Proceedings of 5th International Conference and Exhibition on Design and Production of Machines and Dies/Molds*, 263-267, Kuşadasi, Turkey.

[12] Özel, T., Thepsonthi, T., Ulutan, D., Kaftanoğlu, B. (2011). Experiments and finite element simulations on micromilling of Ti-6Al-4V alloy with uncoated and cBN coated micro-tools, *CIRP Annals – Manufacturing Technology*, Vol. 60, No. 1, 85-88, doi: 10.1016/j.cirp.2011.03.087.