Materials and Design 30 (2009) 414–417

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Technical Reports

Investigation of the wear performance and thermal diffusivity properties of M41 tools steel coated with various film coatings

A.E. Özgür *, B. Yalçın, M. Koru

Technical Education Faculty, Machine Education Department, Süleyman Demirel University, Çünür Campus, 32260 Isparta, Turkiye

ARTICLE INFO

Article history:
Received 13 February 2007
Accepted 6 May 2008
Available online 17 May 2008

ABSTRACT

Ceramic based coatings are used to increase the die and cutting tool life, and to produce quality parts which have surface and dimension sensitive. In this experimental study, the wear performance and thermal properties of the ceramic based coatings were investigated, using the forming tool and cutting tool. M41 high speed steel was coated with TiN, TiAlN, CrN, AlTiN and TiCN by arc physical vapor deposition method (Arc PVD). The wear performance of each coating material was tested by using pin-on ring method. In addition, the thermal diffusivity of the coated steel was measured under thermal load. To be able to understand the probable wear mechanism of the each coating material was carried out. The difference of this work from literature studies is that it uses five different coating types for determination of the thermal diffusivities. Furthermore, an empirical equation was developed for the thermal diffusivity variations with temperature of M41 steel coated with TiN, TiAlN, CrN, AlTiN and TiCN.

1. Introduction

In technical applications, cutting and die tools materials are subjected to complex loading conditions, including thermal, mechanical and wear loading. The life of these materials is dependent upon several factors, such as production method, working conditions, and heat treatment process. Generally, hot or cold work tool steel and high speed steel (AISI M41) have been used as die and cutting tool material [1]. There is no tool material which has both toughness and good wear resistance properties. However, by using several coating techniques, it is possible to produce tool materials having both features.

The coating of tool and dies materials with ceramic based film layers can be conveniently obtained by vapor deposition techniques [10,11]. Especially, arc vapor deposition technique is the most suitable method for this purpose. High speed steel materials have specific features, such as abrasive and adhesive resistance, hot hardness, high fracture strength (toughness). They are also suitable for tiny film coating technologies [2,3]. Ceramic based coatings provide some advantages, including high micro-hardness, low coefficient of friction, preventing of micro cracks propagation, heat resistance, and excellent corrosion strength [4,5,7].

Several studies have been made to determine the optimum coating type for die and forming tool materials. For example Wang [6] used three different (TiN, TiAlN and CrN) coatings for die materials. His results showed that TiAlN and CrN coatings are appropriate coating materials because of their high corrosion resistance [6]. However, Dobrzanski et al. observed that CrN coatings display lowest wear resistance at 500 °C test temperature for hot work steels due to relatively low hardness. They obtained the best wear resistance in TiN coating both at room temperature and at 500 °C test temperature conditions [7]. Bressan et al. investigated wear behaviors of M2 high speed steel and of WC hard metal each coated with TiAlN and TiCN. Their study points out that the wear resistance of TiAlN coating for both materials is superior than TiCN coating [8].

In this study, wear performance and thermal properties of the forming tool and cutting tool coated with ceramic based coatings were investigated. M41 high speed steel was coated with TiN, TiAlN, CrN, AlTiN, and TiCN by Arc PVD method. The wear performance of each coated material was tested via pin-on ring method. In addition, the thermal diffusivity of the coated steels was measured under thermal load.

1.1. The relation between wear and thermal diffusivity

In cutting operation, heat removal from the work material/tool interface is a crucial factor as it determines key factor such as tool wear, removal rate, and work piece quality. While heat generation mainly depends on operation parameters and mechanical properties of the work material, the thermal properties of the cutting tool materials play an important role on heat dissipation.

The tool tip temperature is inversely proportional to its thermal conductivity. Thermal energy dissipation is a function of the thermal conductivity properties of the tool and workpiece materials (Eqs. (1) and (2)). There have been many studies of temperature

* Corresponding author. Tel.: +90 246 2111395; fax: +90 246 2371283.
E-mail address: ozgurae@tef.sdu.edu.tr (A.E. Özgür).

0261-3069/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.matdes.2008.05.020

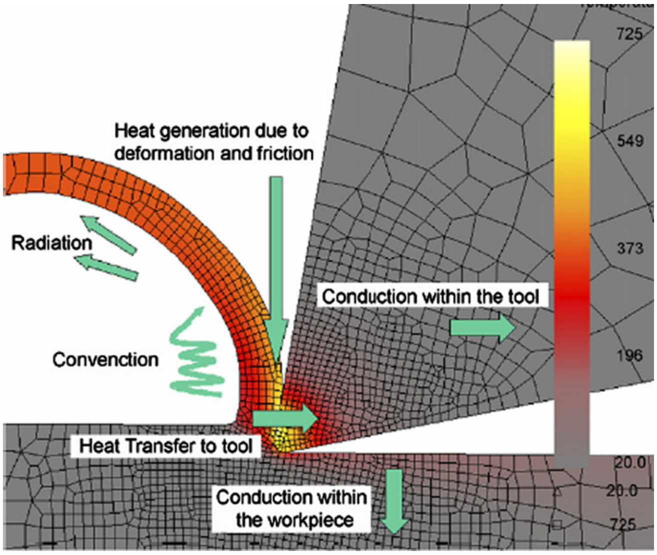

Fig. 1. Heat flux in the cutting tool body [11].

Table 1
Coating condition for all coating materials

Substrate material	Coating type	Current (A)	Temperature (°C)	Time (min)	Voltage (V)	Pressure (Torr)
M41	TiN, TiAlN, CrN, AlTiN and TiCN	50	500	40	450	4.10-5

in the cutting tool. Most commonly, average temperature condition are approximated using the following type of relationship [9];

$$T = u\left(\frac{V \cdot h}{k \cdot \rho \cdot c}\right)^{\frac{1}{2}} \tag{1}$$

Here, T is main temperature (°F) of tool-chip interface, u is specific cutting energy, V is cutting speed, h is undeformed chip thickness, and k, ρ, c are conductivity, density and specific heat, respectively, of workpiece materials. Besides, the relation of thermal conductivity to heat in cutting tool is determined by Herchang et al. [10] with cutting test result;

$$C = \left(\frac{q}{k \cdot 2a}\right) \tag{2}$$

C is empirical temperature, q, frictional heat, k, thermal conductivity of the cutting tool and $2a$ is tool-chip contact width.

In the process of cutting metals, the tool is worn as a result of friction of the chip on the tool face. The cutting action and friction at these contact surfaces increases the temperature of the tool materials which accelerates the physical and chemical associated with tool wear. The relation of the wear and heat flux is determined by Umbrello et al. [11] with results in the study. This relation is given Fig. 1. According to Fig. 1, there is a critical temperature on location where the pressure and friction effects are high. Then the wearing intensifies on this location [11].

2. Experimental procedure

2.1. Test material

Substrate material was high speed steel (HSS), named M41, with the chemical composition (wt.%) of C:1.05, Si:0.45, Mn:0.4, P:0.03, S:0.03, Co:4.8, Cr:3.8, Mo:3.6, W:6.6, V:1.7. The hardness of M41 was HV = 820. Prior to deposition, the substrate material was polished and further cleaned. The coating materials were TiN, TiAlN, CrN, AlTiN, and TiCN They were deposited via arc PVD process by TINKAP Inc. The coating thicknesses change between 1.9 and 2.5 µm. The coating conditions are illustrated in Table 1. The distance between target and substrate was 35 mm.

2.2. Micro-hardness and wear characterization

The micro-hardness and wear characteristics of M41 high speed steel coated ceramic based coatings were investigated. The micro-hardness values were measured with Fischer HP 100 model micro-hardness measurement device. 2.2 g. load was applied on the coating surfaces in 30 s, and 30 s for unloading.

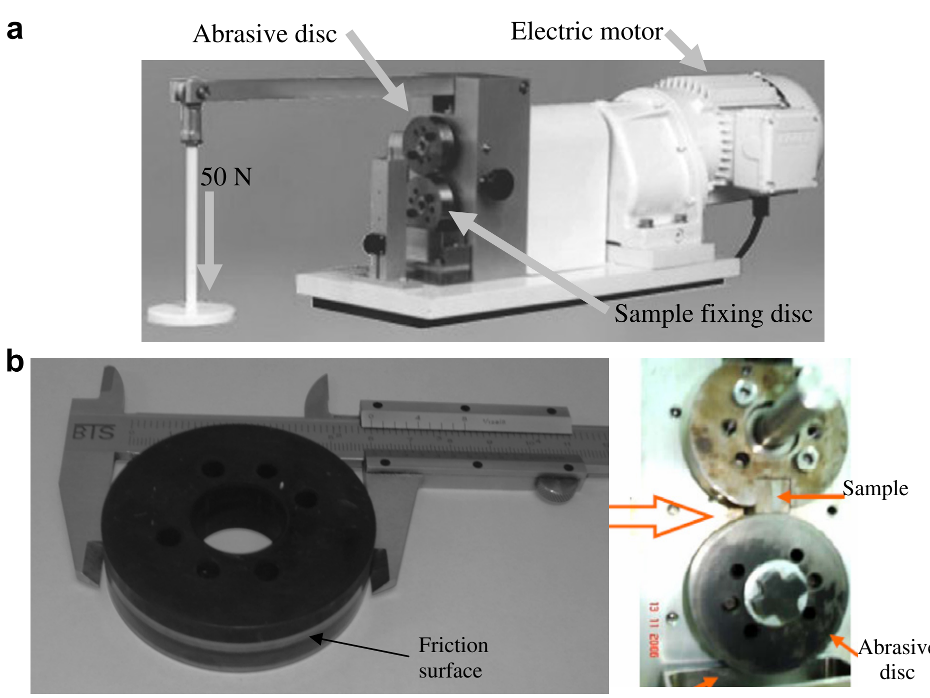

Fig. 2. (a) The TE 53SLIM multi-purpose friction and wear tester and (b) the disc and sample.

The wear mechanisms of the coated materials were investigated with wear and friction device unit showed in Fig. 2. The device model was PLINT TE53 Slim-Multipurpose. The abrasive disc material used in the experimental works was DIN 1.2379 cold work tool steel. The disc was grinded after the volumetric hardening process. Table 2 shows the properties of abrasive disc.

The samples showed in Fig. 2 were prepared with cubic dimensions of 10 × 10 × 10 mm. Dry wear test procedure were applied to the samples with conditions of 50 N load and 4.15 m/s disc spindle speed. At the end of each wearing tests 8000 m. total friction distance were reached. The total mass losses of samples were measured with sensitive devices. The coating wearing resistances were characterized with these mass losses.

2.3. Measuring of thermal diffusivity of coatings

The thermal diffusivity is a term which defines the measure of how quickly a material can carry heat away from a hot source. This term is evaluated by

$$\alpha = \frac{k}{\rho \cdot c} \quad (3)$$

where k is the thermal conductivity (W/m K), ρ is the density (kg/m^3) and c is the specific heat (J/kg K) of the material. All of these values are dependent on the material temperature.

The thermal diffusivity measurements of the coated samples were made by Laser Flash Apparatus Netzsch LFA 457 Micro Flash type device which has adjustable laser power. The device (LFA 457) conforms to national and international standards, such as ASTM E-1461, DIN EN 821 or DIN 30905. The temperature of the sample was adjusted using this device. The thermal diffusivity of the all coated sample materials were measured at 26, 100, 200, 300, 400, 500, 600, 700, 800 °C temperatures. The sample dimensions used for thermal diffusivity measurements are given in Fig. 3 in mm. One surface of the specimens used for the thermal diffusivity measurements was coated. The laser light was applied to this surface.

Table 2
The abrasive disc properties

Chemical composition	C	Si	Mn	Cr	Mo	V
DIN 1.2379 (63 HRc hardness)	1.5	0.25	0.3	11	0.7	1

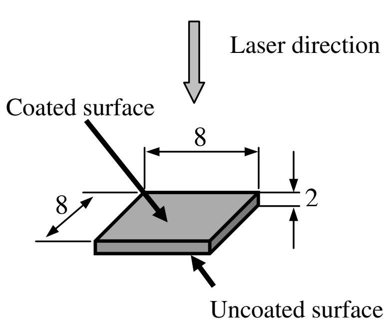

Fig. 3. The dimensions of specimen used for the thermal diffusivity measurements.

3. Results and discussion

The results of Vickers micro-hardness measurements are presented in Fig. 4. The indentation depth of Vickers diamond was around 2–3 μm for all measurements. Therefore, any probable contribution from the substrate material to the hardness values can be neglected. The maximum hardness value was obtained in AlTiN coating. The micro-hardness values of TiCN and TiAlN coatings were equal.

In Fig. 5, the abrasive wear resistance of the various coatings is presented. The best wear resistance was obtained for TiAlN and AlTiN coatings under dry-sliding conditions and 8000 m sliding distance. The wear resistance of TiN coating was almost same with those of TiAlN and AlTiN coatings. On the other hand, the worst wear resistance was obtained for CrN coating, and its wear resistance was similar with TiCN. Although TiAlN coating has lower hardness than AlTiN, it showed nearly same abrasive resistance with AlTiN. This suggests that TiAlN coating should be used where wear resistance is important.

The thermal diffusivity variations of all the coated specimens with temperature were given in Fig. 6. The thermal diffusivity values of all coated specimens are increasing with temperature to about 350 °C. Then, these values start to decrease rapidly with increasing temperature. The values for CrN and TiN coatings are higher than matrix material M41 (HSS). However, the values for TiCN and the matrix material are almost same while the values

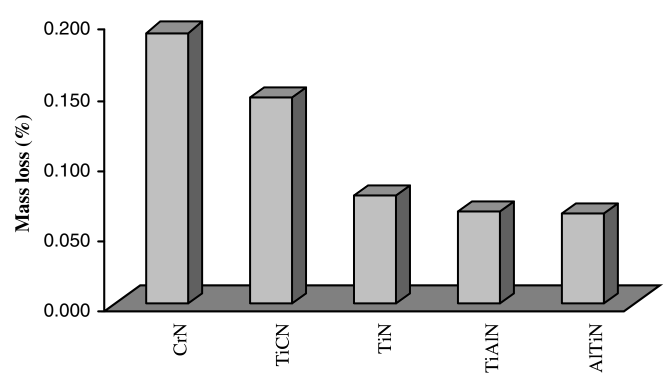

Fig. 5. The total mass loss variations of coated samples for 8000 m. wear distance.

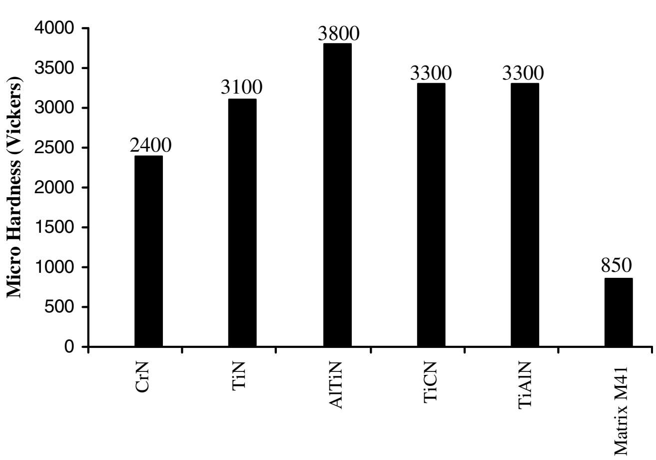

Fig. 4. Micro-hardness values for surface coatings.

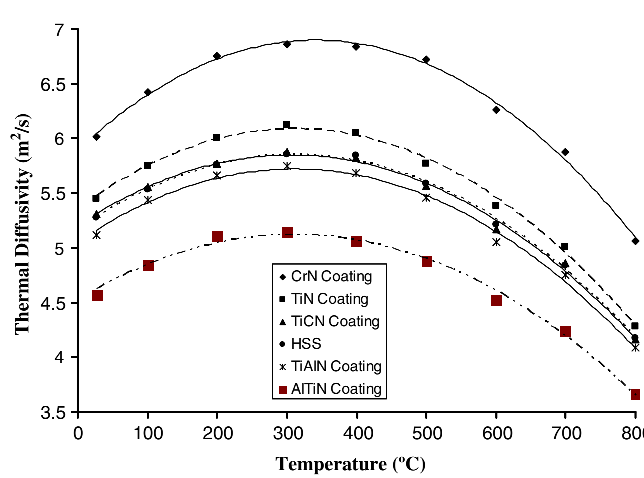

Fig. 6. Thermal diffusivity variations of coated samples with temperature.

Table 3
The constants derived for all coating types in Eq. (2)

Coating type	*c*1	c2	*c*3	*c*4	R^2 (%)
AlTiN	5.71361473E–9	−1.709548348E–05	0.01344454769	1.937229902	99.5
TiAlN	2.152499762E–9	−1.129231102E–5	0.01082201937	2.846282673	99.4
HSS	5.799441139E–10	−8.225836975E–6	0.008990469454	3.296409237	99.7
TiCN	7.150076995E–10	−8.344329674E–6	0.008891690416	3.366831862	99.4
TiN	1.576501276E–9	−1.081670554E–5	0,01090750065	3.10747213	99.6
CrN	−2.706292013E–11	−8.532791987E–6	0.01052784568	3.658338756	99.4

for TiAlN and AlTiN coatings are lower than the matrix material. The lowest thermal diffusivity value was obtained for AlTiN coating.

The empirical equations were developed for all coated materials. They are as follows.

$$\alpha = c_1 \cdot T^3 + c_2 \cdot T^2 + c_3 \cdot T + c_4 \quad (4)$$

c_1, c_2, c_3 and c_4 are the empirical constants that depend on the coating type. These constants are listed in Table 3. The regression value of each equation correlated for the coated materials were very high. The unit of temperature (T) in Eq. (4) is Kelvin.

The variations of the density and specific heat of the matrix material (M41) with the PVD coating operations can be neglected because the thickness values of the substrate material are too high. Therefore the thermal diffusivity variations of the coated M41 steel can be assumed similar to the thermal conductivity variations of the coated M41 steel.

4. Conclusions

In this study we carried out a series of wear resistance and thermal diffusivity tests for different coating types. From the analysis of the experimental results, the following conclusions can be drawn for the wear performance and thermal diffusivity values of the tested PVD coatings;

- The five different PVD film coatings used in the experiments are appropriate solutions for moulds and tools exposed abrasive loads. Under dry-sliding conditions, TiAlN and AlTiN had more wear resistance than other coatings (TiCN, CrN and TiN) which showed similar wear resistance performances.
- The wear values of coated samples decrease with the increasing micro-hardness values. While CrN coated sample which has the lowest micro-hardness was extremely wearing, the lowest wearing was obtained with the AlTiN coated sample which has the highest micro-hardness.
- Depending on the thermal diffusivity values, it is seen that TiAlN and AlTiN coatings are appropriate coating materials for moulds and tools used under thermal loads.
- A recent work showed that, the heat collected on cutting tool decreases with decreasing of the thermal conductivity [11]. Then the tool wear decreased. In this study, the most high wear resistance was obtained with TiAlN coated sample which has the lowest thermal diffusivity and the high micro-hardness.
- Similarly, the highest wear was obtained with CrN coated sample which has the highest thermal diffusivity and the lowest micro-hardness value.
- This study was showed that the coatings work as a barrier to reduce wearing and cutting temperature.

References

[1] Robert AG, Cary RA. Tool steel four editions. USA: American Society for Metal Park; 1980. 644 p.
[2] Oral B, Ece M. Hard ceramic coatings on hot and cold work tool steel and their applications in industry. In: Proceeding of the international seminar on tool steels for moulds and dies, Istanbul, Turkey; 2000. p. 315–20.
[3] Larsson M, Hedenqvist P. PVD coating of forming tools. In: Proceeding of the international seminar on tool steels for moulds and dies, Istanbul, Turkey; 2000. p. 323–25.
[4] Kopac J. Influence of cutting materials and coating on tool quality and tool life. J Mater Process Technol 1998;78:95–103.
[5] Novak R, Kvasnicka I, Novakova D, Mala Z. Study of hard PVD coatings on strongly curved surface. Surf Coat Technol 1999;114:65–9.
[6] Wang Y. A study of PVD coatings and die materials for extended die-casting die life. Surf Coat Technol 1997;94:60–3.
[7] Dobrzanski LA, Polok M, Adamiak M. Structure and properties of wear resistance PVD coatings deposited onto X37CrMoV5-1 type hot work steel. J Mater Process Technol 2005;164–165:843–9.
[8] Bressan JD, Hesse R, Jilva Jr EM. Abrasive wear behavior of high speed steel and hard metal coated with TiAlN and TiCN. Wear 2001;250:561–8.
[9] ASM metal handbook, Machining, vol. 16, 9th ed. USA: ASM International Organization; 1998. p. 37–40.
[10] Herchang A, Yang WJ. Heat transfer and life of metal cutting tools in turning. Int J Heat Mass Transfer 1997;41(3):613–23.
[11] Umbrella D, Filice L, Rizzuti S, Micari F. On the evaluation of the global heat transfer coefficient in cutting. Int J Machine Tool Manufact 2007;47:1738–43.