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RESEARCH

Comparison of Wear Behaviours of Cathodic Arc TiN, TiAlN Coated and Uncoated Twist Drills Under Aggressive Machining Conditions

Recent advances in cutting tool materials and PVD surface coatings are making high-speed dry machiningan increasingly viable machining operation in commercial manufacturing sectors. In this investigation, the performance of cathodic arc TiN and TiAlN coatings was assessed on HSS twist drills used to machine 1015 and 2080 workpiece materials under aggressive machining conditions. 17.6-26.4 m/min cutting speeds and 0.10-0.15 mm/rev feed rates were used as cutting parametersand all the experiments conducted under dryconditions. Number of holes drilled by TiN, TiAlNcoated and uncoated tools observed and TiN coating was found to be superiour than the others. The drill wear was observed using scanning electron microscopy (SEM) and also macroscopy, and comparative wear properties were discussed.

Keywords: Cathodic arc deposition, TiN, TiAlN, tool wear, dry cutting.

1. INTRODUCTION

Metal cutting is characterized by the large strain and high temperature appears near the cutting edge of the cutting tools [1]. Wear resistance, thermal stability such as oxidation resistance and hardness at elevated temperatures are key issues within these cutting operations [2]. There have been numerous articles published in the literature reporting the benefits of Ti-based thin films in drilling operations [1,3-20]. For drilling, 97–99% of work is transferred into heat. Under dry cutting, the heat will accumulate and result in a dramatic thermal wear of the cutting edge. Thus, besides hardness and strength, the thermal stability of the coating is also very important for cutting tools. The bare HSS tool is not fit for dry cutting and coatings should be employed [1,21]. Advances in manufacturing technologies (increased cutting speeds, dry machining, etc.) triggered the fast commercial growth of PVD coatings for cutting tools. On the other hand, technological improvements in coating technologies (TiAlN, AlTiN, AlCrN and nanocomposite coatings) enabled these advances in manufacturing technologies [2]. HSS drills with refractory coatings (TiAlN and multilayer) tend to produce holes closer to the ideal radius than the uncoated drills due to the superior thermal barrier provided by these coatings, discouraging drill substrate expansion [8].

TiN has the NaCl-type crystal structure, possessing advantages of high hardness, high chemical stability, and excellent adhesion to substrates, which make TiN the most popular film used on cutting tools and forming molds [6]. However, TiAlN is a very promising material for wear resistant coatings because of its excellent high temperature corrosion and oxidation resistance which results in higher chemical stability, in comparison to TiN. The incorporation of aluminium in the cubic facecentered TiN structure on Ti sites leads to deformation and strengthening of the crystal structure of the coating. Consequently the compressive stress is larger compared to TiN coatings [3,7]. In metal cutting, drilling conditions have a significant effect on tool life, productivity and workpiece quality. The purpose of this study is to investigate the wear mechanisms of cathodic arc TiN and TiAlN coated tools in drilling 1015 and 2080 workpiece materials under aggressive machining conditions and to discuss comparative wear properties.

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2. EXPERIMENTAL DETAILS

TMC-500V machining center built by the Taksan, Turkey was employed to drill 20 mm depth holes on 1015 and 2080 workpiece materials. Chemical composition and hardness of the workpiece materials are given in Tab. 1 and Tab. 2, respectively. Twist drills (Ra=0.22 μm) made by Evar in M2 grade HSS steel were used for the experimental work. The drills, corresponding to DIN 338 standard, had a diameter of 7 mm and a point angle of 118°. The coatings were deposited using the cathodic arc system showed in Fig. 1. The deposition parameters and the properties of the coatings are given in Tab. 3 and Tab. 4, respectively. The thickness of the coatings were measured using CSEM-Calotest apparatus. EDX analysis of the coatings are given in Fig. 2. Drilling conditions are: V=17.6 m/min (800 rpm), f=0.10 mm/rev and V=26.4 m/min (1200 rpm), f=0.15 mm/rev for both 1015 and 2080 steels (Tab. 5). All cutting tests were carried out without coolant. Number of holes drilled by TiN, TiAlN coated and uncoated tools were observed. Also, average surface roughness Ra values of the holes were measured by Mitutoyo Surftest-211 apparatus. The drill wear was observed using scanning electron microscopy (SEM) and also macroscopy.

Tab. 1: Chemical composition of workpiece materials

Element (Wt.%)	C	Si	S	P	Mn	Ni	Cr	Mo	Cu	Fe
1015	0.1326	0.1940	0.0309	0.0186	0.6333	0.1045	0.0732	0.0137	0.3780	Bal.
2080	2.0827	0.1939	0.0011	0.0252	0.2708	0.0996	11.5627	0.0677	0.0429	Bal.

Tab. 2: Hardness of workpiece materials

Material	Rockwell A (HRA)	Vickers (HV)
1015	45.5	132
2080	60	235

Tab. 3: Cathodic arc deposition parameters.

Coating type	Current (A)	Coating period (min)	Voltage (V)	Pressure (torr)
TiN	50	60	200	3.0×10^{-5}
TiAlN	50	25	200	8.0×10^{-5}

Tab. 4: TiN and TiAlN coating properties.

Coating type	Thickness (μm)	Hardness HV	Surf. Roughness Ra (μm)
TiN	3.16	2800-3200	0.28
TiAlN	2.92	3000-3400	0.34

Tab. 5: Cutting conditions for the drills.

Drill size (mm)	Ø 7 (DIN 338)
Workpiece materials	AISI 1015-AISI 2080
Cutting speeds V (m/min)	17.6 (800 rpm) 26.4 (1200 rpm)
Feed rates f (mm/rev)	0.10 – 0.15
Depth of cut (mm)	20 (through hole)
Coolent	None

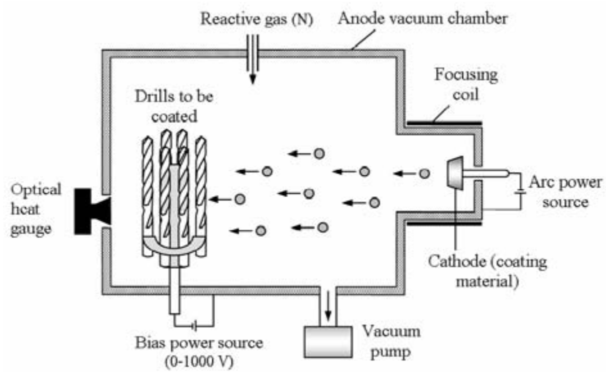

Fig. 1: Schematic illustration of the cathodic arc system

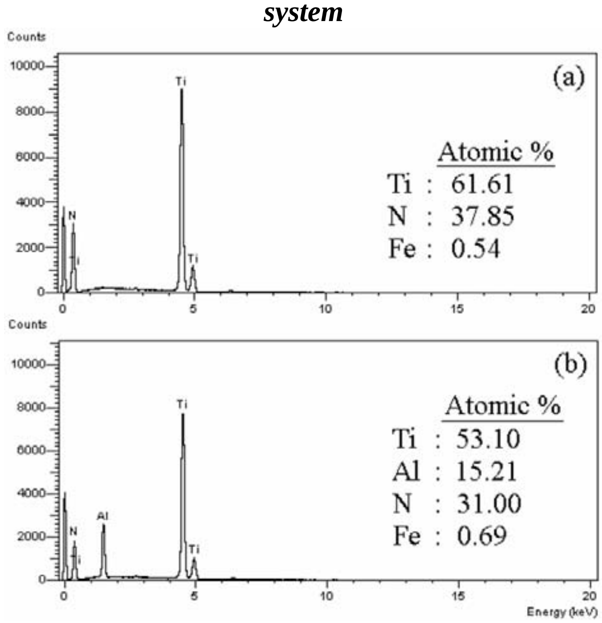

Fig. 2: EDX analysis of the coatings: (a) TiN coating, (b) TiAlN coating

3. RESULTS

The drilling tests showed that, when drilling 1015 steel, TiN, TiAlN coated and uncoated tools were able to drill 30 holes in both drilling conditions (Fig. 3). When drilling 2080 steel in the cutting condition of *V*=17.6 m/min (800 rpm), *f*=0.10 mm/rev, the number of holes drilled by TiN coated tool was 29 when which drilled by TiAlN and uncoated tools were 19 and 3, respectively. However, in the cutting condition of *V*=26.4 m/min (1200 rpm), *f*=0.15 mm/rev, the number of holes drilled by TiN coated tool was 11 when which drilled by TiAlN and uncoated tools were 4 and 1, respectively. TiN coating was found to be superiour than the others. End view of the drills used in the experiments are given in Fig. 4.

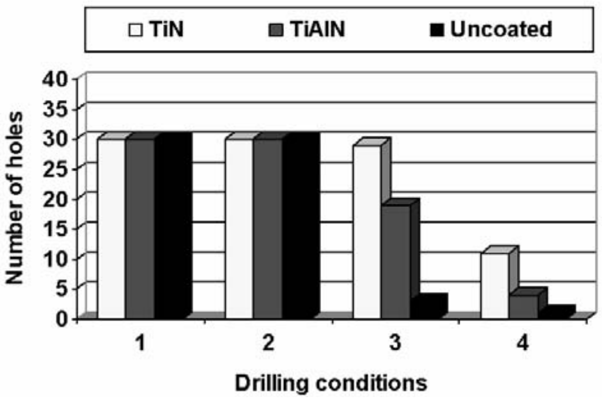

Fig. 3: Number of holes drilled by TiN, TiAlN coated and uncoated tools. Drilling conditions (1) 1015, n=800 rpm, f=0.10 mm/rev, (2) 1015, n=1200 rpm, f=0.15 mm/rev, (3) 2080, n=800 rpm, f=0.10 mm/rev, (4) 2080, n=1200 rpm, f=0.15 mm/rev

It can be seen from Fig. 5 that surface roughness of the holes drilled by TiN, TiAlN coated and uncoated tools are very changeable. It was due to increasing of force and temperature and formation of chip clogging. Chip clogging, defined as the adherence of the chips to the flutes, was observed in all the drilling tests. In the worst case, extreme welding to the drill flutes and drill breakage were observed. Nevertheless, the surface roughness of the holes increases slightly with increase in the number of holes drilled and the resulting holes formed by TiAlN coated drills are smoother than those formed by TiN coated and uncoated drills.

Because of the aggressive machining conditions, friction force is the most important factor governing tool failure. The use of cutting fluid in drilling can effectively reduce friction force and increase the tool life. The summary of the drills used for the experimental work is given in Fig. 6. Fig. 7 shows SEM micrograph of the TiN coated drill (n=1200 rpm, *f*=0.15 mm/rev, 2080 steel, after 11 holes). Fig. 8 shows SEM micrographs of the TiAlN coated drill (n=800 rpm, *f*=0.10 mm/rev, 2080 steel, after 4 holes).

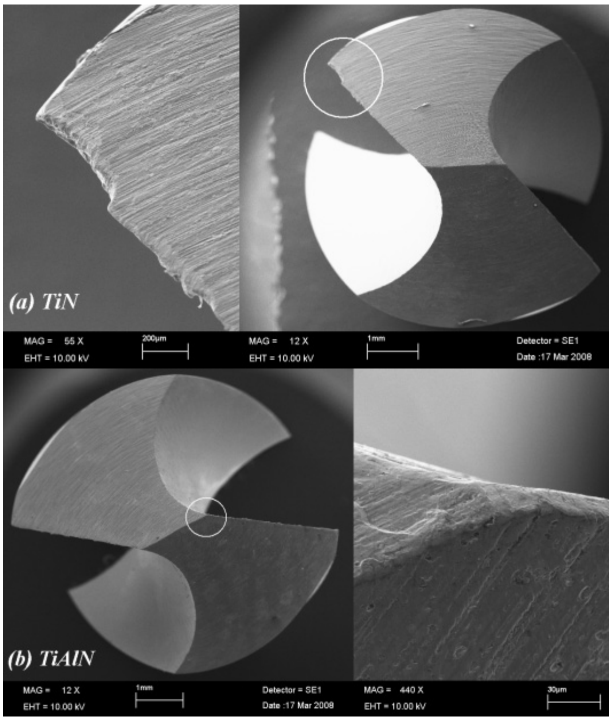

Fig. 4: End view of the drills used in the experiments: (a) TiN, (b) TiAlN (n=800 rpm, f=0.10 mm/rev, 1015 steel, 30 holes)

Fig. 9 shows end view of the uncoated drill (n=800 rpm, *f*=0.10 mm/rev, 1015 steel, after 30 holes). Wear mechanisms are coating layer abrading-off, microcracking of the cutting edges, chip clogging and breakage of the drills.

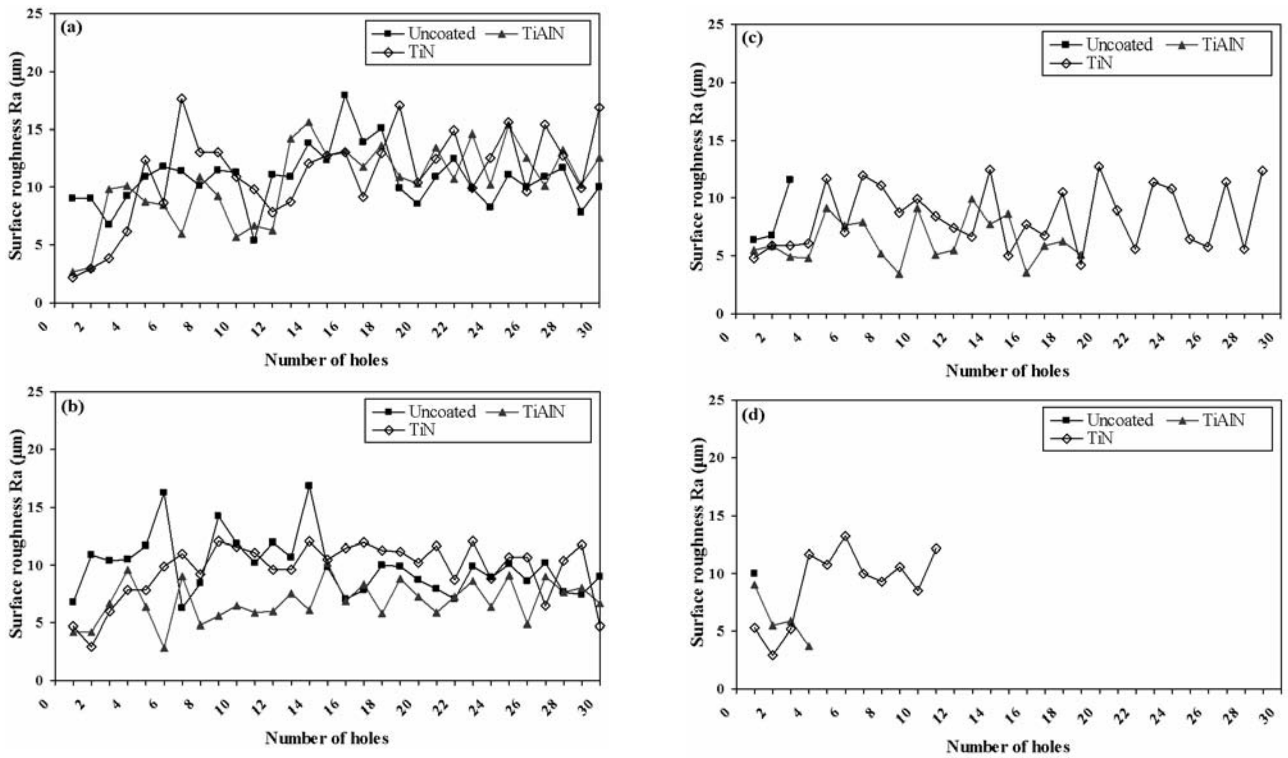

Fig. 5: Surface roughness of the holes drilled by TiN, TiAlN coated and uncoated tools. (a) 1015, n=800 rpm, f=0.10 mm/rev, (b) 1015, n=1200 rpm, f=0.15 mm/rev, (c) 2080, n=800 rpm, f=0.10 mm/rev, (d) 2080, n=1200 rpm, f=0.15 mm/rev

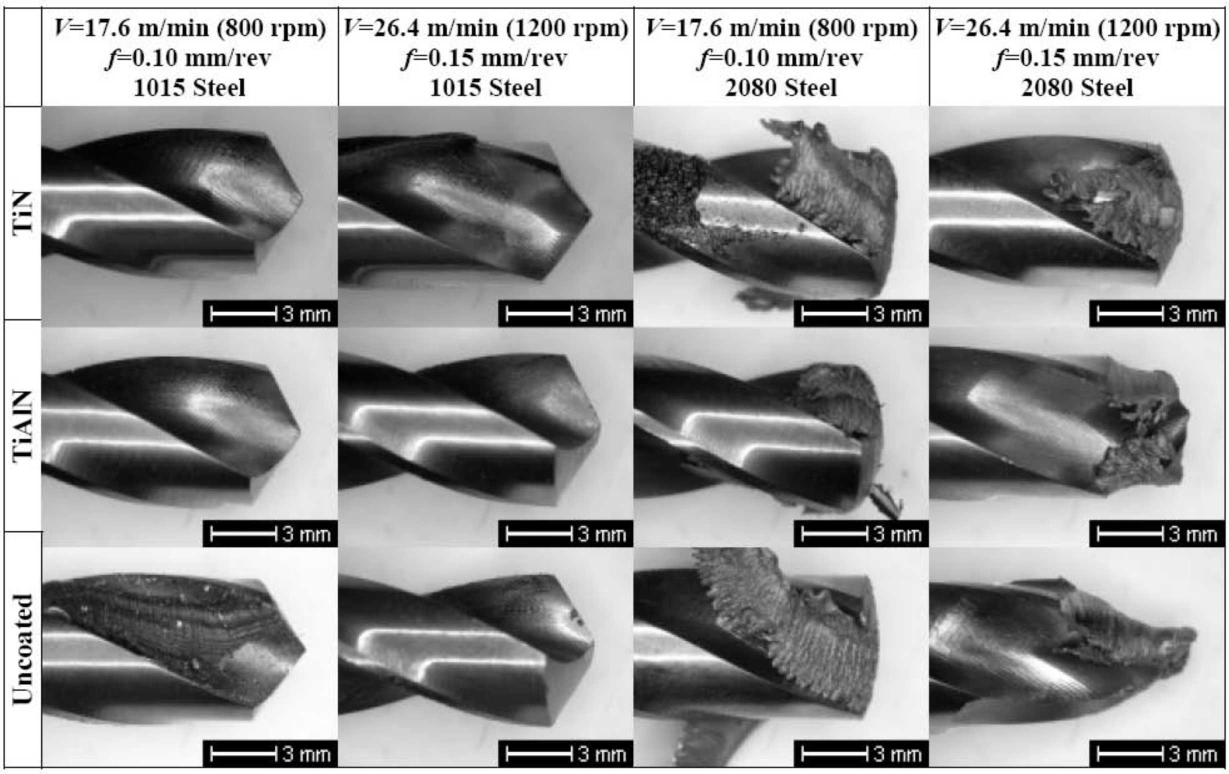

Fig. 6: The summary of the drills used for the experimental work

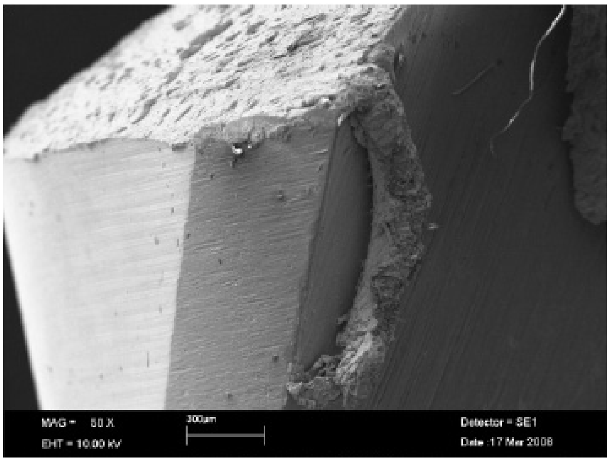

Fig. 7: SEM micrograph of the TiN coated drill (n=1200 rpm, f=0.15 mm/rev, 2080 steel, 11 holes)

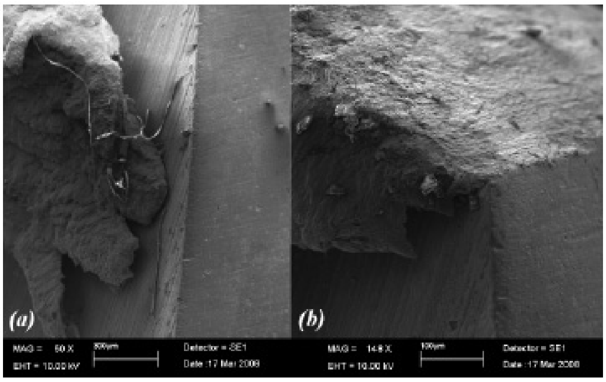

Fig. 8: SEM micrographs of the TiAlN coated drill: (a) edge view, (b) tip corner view (n=800 rpm, f=0.10 mm/rev, 2080 steel, 4 holes)

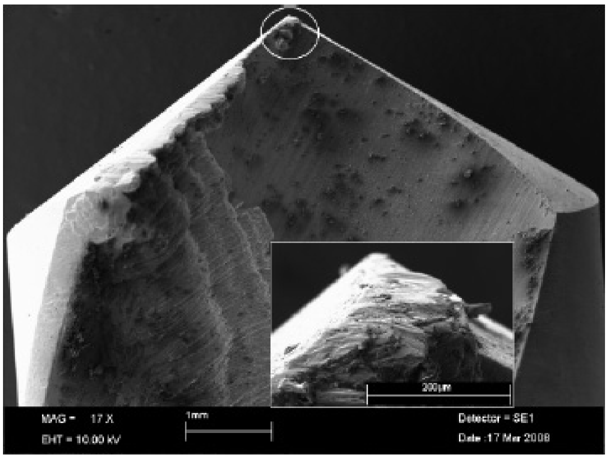

Fig. 9: End view of the uncoated drill (n=800 rpm, f=0.10 mm/rev, 1015 steel, 30 holes)

CONCLUSIONS

In the present investigation, the performance of TiN, TiAlN coated and uncoated tools in an aggressive drilling operation was observed. The results of this investigation are as following:

1. TiN and TiAlN coatings improve dry cutting capability of the M2 HSS drills even under aggressive machining conditions.
2. Although TiAlN coatings have high oxidation resistance and relatively low friction coefficient TiN coating was found to be superiour than TiAlN coating as number of holes drilled under the conditions used in this study. It can be attributed to larger compressive stress of TiAlN coating which leadsearly coating layer abrading-off under aggressive conditions.
3. However, the resulting holes formed by TiAlN coated drills are a bit smoother than those formed by TiN coated and uncoated drills.
4. Main wear mechanisms of the drills are coating layer abrading-off, micro-cracking of the cutting edges, chip clogging and breakage of the drills.
5. As the cutting conditions are very changeable in drilling operations further machining tests have to be done to understand the wear properties of these coatings better.

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