TRANSVERSE RUPTURE STRENGTH OF SOLID LUBRICANT CUTTING TOOL MATERIAL

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Abstract

Solid lubricant bearings and gears find many engineering applications due to its clean environment and maintenance free characteristics. Solid lubricant based cutting tool has potential to replace conventional cutting tool under dry machining. In this work, tungsten carbide based material with various weight percentage of solid lubricant, calcium fluoride was considered. Cobalt and stearic acid were considered for binder and process control agent respectively. Materials were milled in the planetary ball mill and milled powders were compacted uniaxially and sintered in a tube furnace. Developed materials were evaluated for the transverse rupture strength with the aid of developed fixture and servo hydraulic universal testing facility. From the investigation, tungsten carbide with 5 wt.% calcium fluoride found to be superior over other investigated materials. Failure morphology of the fractured test specimen reveals the role of solid lubricant over transverse rupture strength.

Keywords: Transverse Rupture strength, Solid Lubricant, Cutting Tool.

1 Introduction

Tungsten carbide based metals have been used for cutting tools and other wear-resistant components due to its high hardness, good strength, excellent wear and erosion resistance. Transverse rupture strength (TRS) is used as an index for the strength for cutting tool materials. Various research investigations have been conducted to improve this strength as well as tribological performance with ultra fine size particles, reinforcements, surface coating and material addition. Goudarzi and Akhlaghi (2013) studied the effect of nanosize silicon carbide (2.5-7\%\(^\) with pure aluminium. With the increase in silicon carbide amount, milled particle size found to reduce with increase in flowability. Fine size particles contribute to the increased density and micro hardness. Similar behaviour is also observed with aluminium magnesium matrix. Sharifi \textit{et al}. (2011) developed and evaluated the mechanical properties of aluminium reinforced with boron carbide (5-15\%). With the increase in boron carbide, hardness found to increase due to the presence of extremely hard phase as well as reduction in particle size. Tousi \textit{et al}. (2011) studied the effect alumina (1-7 \%) on aluminium. With the increase in alumina, hardness of the composite found to increase due to the presence of hard particles. Lin \textit{et al}. (2012) studied the effect of molybdenum (1\%) on mechanical properties of WC-TiC-Ni cemented carbides. Density and transverse rupture strength were found to decrease, due to the presence of pores. Liu \textit{et al}. (2006) studied the effect of TiC and TiN (0-10 \%) on the mechanical properties of titanium carbo nitride based cermets. With the addition of TiC, TRS found to increase upto 10\% due to its greyish ring microstructure and ceramic phase. TRS found to increase with addition of TiN upto 5\%, and decreases beyond due to the release of nitrogen and formation of pores. Liu \textit{et al}. (2003) studied the effect of Mo (4-12 \%) on the mechanical properties of TiC based cermets with nano TiN. Due to the coarser ceramic phase of Mo, flexural strength of the cermet found to reduces. Fractography of the test specimen revealed trans-granular and inter-granular fractures. Wang \textit{et al}. (2010) studied the influence of Mo (1-7\%) on the microstructure and mechanical properties of TiC-based cermets. Mo found to improve the wettability and refine the grains of the hard phase. Transverse rupture strength found to increase with increase in Mo. Momozawa \textit{et al}. (2012) investigated the effect of manganese (1-5\%) over TiC/TiB\(_2\) base cermets. Hardness and TRS found to increase upto 1%. Beyond this amount, manganese evaporates and form residual pores resulted in reduction of TRS. Song \textit{et al}. (2014) reported the effect of titanium carbide (10-30 \%) on ternary titanium boride. Higher amount of titanium carbide lowers the pores; increases density thereby increases micro hardness and flexural strength. Suzuki and Hayashi (1966) studied the effect TiC(6-17 \%) in
the tungsten carbide material. 6 % TiC alloy exhibited higher strength than that of 11 and 17 %. Beyond this amount, TRS found to decrease due to the poor wettability. Martin et al. (2007) investigated the uniaxial compaction of bismuth-tantalum composites. Ta is considerably harder and stiffer than Bi. Yield strength of the composite found to increase up to 0.3 % of Ta and decreases beyond. Deng et al. (2005) studied the effect of solid lubricants, CaF₂, MoS₂ and BN (5-15 %) content on flexural and hardness of Al₂O₃/TiC composites. With the addition of these solid lubricants, hardness as well as flexural strength found to decrease due to the formation of micro crack in the sintered materials. From the literature, it is observed that reinforcement and solid lubricant has considerable effect on mechanical strength. Hence there is a need to understand the effect of solid lubricant amount on the mechanical strength of the proposed tungsten carbide based solid lubricant materials.

2 Experimental Procedure

Commercially available tungsten carbide (WC) of 15-18 µm size with 99.8% purity (Rapicut carbides) is considered as a base material. Cobalt (Co) of 20-30 µm size with 99.5% purity (Loba Chemie) is considered as a binder material. Calcium fluoride (CaF₂) of 170-180 µm size with 98% of purity (Loba Chemie) is considered as a lubricant material for the proposed cutting tool material. Planetary ball milling and the ball-milling time was selected as 40 hrs, the weight ratio of ball-to-powder was 5:1, and the rotation speed was 210 RPM. Plate speed and powder ball ratio was decided so as to avoid contamination and reported elsewhere (Senthilvelan and Robi (2008)). Tungsten carbide was milled with 10 wt% of cobalt and 3-10 wt% of calcium fluoride for 40 hrs in the planetary ball milling. 4 wt % of stearic acid was added to avoid cold welding during milling. Milled powders were compacted at 400 MPa with the aid of uniaxial tensile testing machine (UTE 20). Later green compacted specimens 40 × 16 × 5 mm size as per the ASTM B331-95 for transverse rupture strength evaluation and sintered at 1450°C in a tube furnace (Bysakh, Okay 70T7) under nitrogen atmosphere. Density of the sintered specimen was measured by the Archimedes’ method (ASTM B962-08). Sintered sample surface was grounded and polished to check hardness with the aid of Rockwell hardness tester (FIE, RASN (E)). Diamond indenter of scale A with 60 kgf load was utilized. Detailed milling and characteristics of the proposed material were reported elsewhere (Muthuraja and Senthilvelan 2014).

3 Results and Discussion

3.1 Basic Material Characteristics

To understand the effect of solid lubricant, various amount of calcium fluoride (3, 5, 7 and 10 wt %) were considered for the development of tungsten carbide based solid lubricant material. Figure 1 shows the effects of solid lubricant on the relative density and Rockwell hardness of the sintered composites. With the addition of CaF₂, hardness and density initially decreases then increases and finally decreases. Among the considered materials, WC with 5 % CaF₂ exhibits superior hardness as well as density. From the results, it is observed that insufficient and excessive amount of CaF₂ hamper the compressibility which results in poor density and hardness. Kato et al. (2003) as well as Lu et al. (2001) also observed similar behaviour in their investigations.

![Figure 1 Density and hardness of the test material.](image)

Kato et al. (2003) reported the effect of MoS₂ (5-40%) on the tribological behaviour of copper-tin composites. It is observed that composite hardness found to increase up to 5 % of MoS₂, above which hardness found to decrease due to the excessive brittle sulphur phase and pores. Lu et al. (2001) developed Ni/CeF₂/graphite composites with different amounts of graphite (1-5 %) and evaluated tribological performance. Hardness found to increases up to 3 %, and decreases beyond. Li et al. (2008) reported the effect of Mo (5-15 %) on the hardness of titanium carbo nitride cermets. With addition of Mo, hardness found to increase then decreases beyond 10 %. This behavior is due to the refinement of grains up to 10 % and no such grain reinforcement beyond 10 %.

3.2 Transverse Rupture Strength

Sintered test specimens were evaluated for its transverse rupture strength through three point bending test with the aid of servo hydraulic dynamic testing
machine (Instron, 8801J). Figure 2 shows the developed fixture and tests were carried out as per the ASTM B406-96. Transverse rupture strength TRS = 3PL/2bh², where TRS is in MPa; P is the applied force to fracture in N ; L is the distance between two parallel supports, mm; b and h is the width and height of the samples respectively in mm. At least three trails were carried on every material to evaluate TRS.

Figure 2 Developed fixture for TRS evaluation

Figure 3 shows the effect of solid lubricant on the transverse rupture strength. TRS also exhibit similar behaviour as hardness and density.

Figure 3 Effect of solid lubricant on transverse rupture strength

With the addition of CaF₂, TRS initially reduces then increases then finally decreases. At 0 and 3 % (insufficient CaF₂) as well at 10 % (excessive CaF₂) poor bonding between tungsten carbide particle is exhibited and confirmed by the presence of spherical agglomerates at the fractured surfaces.

Figure 4a shows the spherical shape agglomerates in the fractured surface of WC-Co without CaF₂. Presence of spherical agglomerates confirms the sintering defects. Similar features were also observed at the fractured surface of WC-Co with 10 % CaF₂.

Figure 4b shows the spherical shape agglomerates in the fractured surface of WC-Co with 5 % CaF₂. Presence of spherical agglomerates confirms the sintering defects. Similar features were also observed at the fractured surface of WC-Co with 10 % CaF₂. The fractured surface of WC-Co with 5 % CaF₂ (Figure 4b), doesn’t show any such defect particles were observed with good bonding at grain boundaries. Gu and Shen (2007) observed similar spherical agglomerates called balling phenomenon while laser sintering copper based metal powder. During sintering, excessive melting reduces the surface energy and melt break up into agglomerates of spherical shape. Li et al. (2012) also observed balling behavior while laser sintering stainless steel and nickel powder due to the poor wetting resulted in inferior sintering. In sufficient
and excess amount of CaF$_2$ deteriorates wetting as well as contributes to the excess melting. Beyond 5% CaF$_2$, transverse rupture strength of tungsten carbide material reduces. Poor bonding was observed on test material having more than 7 wt.% of CaF$_2$ due to presence of more soft materials in the boundaries of WC and Co. Kato et al. (2003) and Lu et al. (2001) also observed similar strength behavior with graphite. Kato et al. (2003) reported the effect of graphite (5-40%) on the bending strength of copper-tin composites. With the increase in graphite upto 5%, an increase in bending strength is observed then drops down due to the generation of pores. Lu et al. (2001) developed Ni/CeF$_3$/graphite composites with different amounts of graphite (1-5%) and evaluated the mechanical performance. Compressive strength increases upto 3% due to the formation of carbide phase and decreases beyond this value due to the nonexistence of carbide phase. Huang et al. (2009) studied the influence of solid lubricants, BaF$_2$,CaF$_2$ (5-20%). With the increase in BaF$_2$, hardness and TRS found to reduces due to the poor interparticle adhesion. Li et al. (2008) reported the effect of Mo (5-15%) on the bending strength of titanium carbonitride cerments. It was found that the bending strength increased with the increase of Mo content due to the improved wettability between ceramic and metallic phase.

To confirm the presence of all added metals, EDX was taken. Figure 5 shows EDX data of WC-Co with 7 wt. % CaF$_2$. It is confirmed that white phase (points A) was showing all components, the another white phase (point B) was calcium fluoride, grey phase (point C, D) showing WC and all components respectively. Result revealed the presence of solid lubricant in fractured specimen after sintering.

![Figure 5 Energy Dispersive X-Ray analysis showing the presence of included material](image)

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Conclusion

Present study reveals significant effect of solid lubricant calcium fluoride on density, hardness and transverse rupture strength of tungsten carbide based solid lubricant material. Tungsten carbide with 5% calcium fluoride exhibits superior density, hardness and transverse rupture strength.

References


