Post Graduate Research Papers 2001/2002
School of Materials & Mineral Resources Engineering, USM

THERMAL SPRAY FABRICATION OF LOW COST CUTTING WHEELS

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ABSTRACT

The main objective of this work was to produce low cost cutting wheels using thermal spray fabrication technique. The aim is to bond hard particles (silicon carbide) on cutting wheels (martensitic alloy steel) to enhance the cutting capability by means of solidification, thermal spray and polymer bonding. The low cost cutting wheels can be produce by means of process and materials used are cheap. It was found that the wheel produce from this technique is suitable for cutting metals such as copper and steel.

INTRODUCTION

Ceramic coatings are often used to provide increased resistance to wear, erosion and corrosion in engineering components. Silicon carbide coatings are attractive for applications where the service requirements can be severe. In recent years, silicon carbide wear coatings have been employed in the cutting tool industry to protect both cemented carbide and ceramic cutting tool inserts, metal working tools and high speed drilling or milling bits [1]. During thermal spraying, the carbide and metal particles travel separately to the target through the flame. Whilst the metal particles may be molten or semi-molten when they arrive at the target, the carbide particles will be solid and their ability to be incorporated into the coating will depend upon arriving at the target at a similar time and position to some molten or semi-molten metal [4].

MATERIALS AND METHODS

In this research, martensitic alloy steel are used as substrate materials which have compositions 0.9%C, 1.3%Mn, `0.5%W, 0.5%Cr and 0.2%V. SiC powder is used as abrasive powder and the powder is grind and sieve with 38μm sieve. Nickel-chromium (Ni-Cr) alloy powder size (50-160μm) is used as thermal spray powder. This powder is mixed together with silicon carbide powder (30% SiC and 70 % Ni-Cr) during thermal spray process as a coating material.

Coating process using thermal spray;
Firstly, the surface of wheel is clean then the wheel is sandwich between two pieces of mask to prevent the coating material to deposit on the surface of the center of the wheel. Then, thermal spray is applied. Finally the coated disc was cooled to room temperature in the air. In order to enhance the adhesion between the coated layer and the substrate, a thin layer of epoxy resin is applied on the top of the coated layer. Before that, the resin was mixed with silicon carbide powder with 1:1 ratio. Fig 1 shows the coated cutting wheels. The test mainly conducted on the cutting machine with following variables; load, speed of cutting and their influence on depth of cutting. Work piece materials are copper, steel and ceramic.

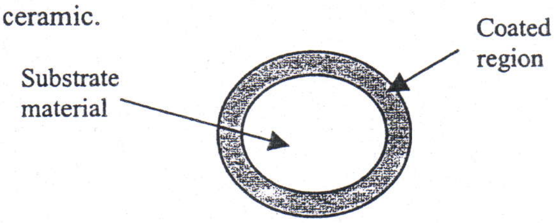

Fig 1: Wheel produce by thermal spray technique.

RESULTS AND DISCUSSIONS

Firstly, testing was done to the soft material like copper as a work piece for speed 250rpm. Generally, for the fresh wheel, depth of cut is increase with increasing the load (fig 2).

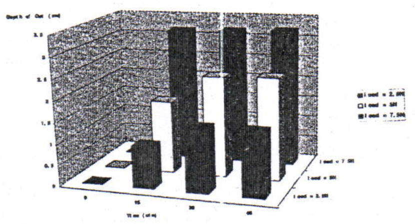

Fig 2:Depth of cut Vs time at speed 250rpm for sample copper.

This behavior is due to the fact that, the higher load will increase the feed force to the wheel and also the contact area is increase which means increase in depth of cut. Feed force is the force that acting to the tool in the direction parallel with the direction of feed.

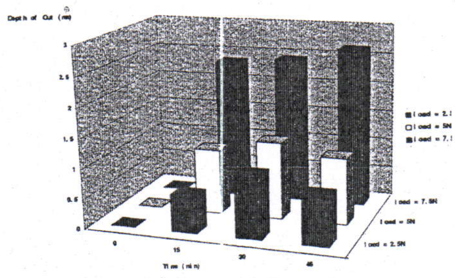

Fig 3: Depth of cut Vs time at speed 250 rpm for sample steel.

Fig 3 shows depth of cut for steel as a work piece used for speed 250rpm. The behavior is almost the same as the soft materials, which the depth of cut is increase with increasing the load. But the depth of cut for steel is lessening than for the copper. This is due to the steel is hard material compare to the copper. From the figure 2, depth of cut reduces about 50% for 5N load compare to the highest load 7.5N. This mode happens for all lowest to the longest time. It can be explained that, the coating hard particle is worn out during cutting the copper and steel with highest load, because steel is hard material compare to the copper.

Testing is continue with the ceramic as a workpiece, but we only get about 0.01mm depth of cut and this wheel is not suitable to cutting the ceramic material. Testing was carry on to the higher speed 300rpm for all the workpieces, however fluctuating results were obtain, due to lost some of the hard coating materials during cutting hard sample such as steel and ceramic in the first stage.

CONCLUSION

The wheels produce in this research only suitable for cutting metal such as copper and steels and not suitable for cutting ceramic materials. The performance of the wheel is very good when the hard coating is still adhere to the substrate and not worn out.

ACKNOWLEDGEMENT

The author likes to send deep thanks and appreciation to the respectful teacher and supervisor Assc. Prof. Dr. Luay Bakir Hussain for sharing his expertise, support and also appreciation to all lecturers of School of Materials and Mineral Resources for their teaching and guidance.

REFERENCES

1. B.V Tanikella, K.A Gruss, R.F.Davis, R.O Scattergood, 1996, *Indentation and Microcutting Fracture Damage in a Silicon Carbide Coating on an Incoloy Substrate,* Journal Surface and Coatings Technology Vol 88.
2. C.H. Che Haron, A. Ginting, J.H. Goh, 2001, *Wear of coated and Uncoated Carbides in Turning Tool Steel*, Journal of Materials Processing Technology Vol 116.
3. E.M.Trent, 1991, *Metal Cutting Third Edition*, Butterworth –Henemann Ltd.
4. S.Wirojanupatump, P.H.Shipway, D.G. McCartney, 2001, *The Influence of HVOF Powder Feedstock Characteristics on the Abrasive Wear Behavior of Cr_xC_y-NiCr Coatings*, Wear Vol.249.

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THERMAL SPRAY DEPOSITION TO PRODUCE STEEL CUTTING WHEELS.

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ABSTRACT

The target of this study was to produce cutting wheel and study the performance of cutting behavior. Thermal spray bonding technology was used to produce low alloy steel and stainless steel cutting wheels. Two different types of powder (Al-Si, Ni-Cr-B) as bonding agent and diamond as abrasives for both steels were used. Low alloy steel was discarded due to its low cut of depth performance. However, stainless steel coated by two types of powder has reached acceptable testing stages. Wear rate (mg/cm^2) and related tests have been carried out for different load and speeds as function of time, whereas the wear rate shows high dependency on operating conditions as well as the powder type.

INTRODUCTION

Diamond/cubic boron nitride abrasive products are noted for high durability and wear resistance making them economically attractive and particularly suitable for range of industrial application such as tool sharpening deep grinding of difficult-to-machine materials. These physical characteristics of diamond and CBN allow an increase in the productivity by taking large depth of cut with less metallurgical work-piece damage (increased quality). When compared to conventional abrasives they also give longer wheel life, lowering the overall cost [1].

The abrasive materials industry interfaces directly with the heavy industries, particularly the iron and steel, automotive, and construction industries through the widespread use of abrasive products for grinding, cutting, polishing and finishing operations. The industry is characterized by wide variation in its production technologies from ordinary mining, grinding and sizing operations to high-temperature, high-pressure synthesis for diamond and cubic boron nitride. Certain segments of the industry are characterized by rapid innovations and technological changes. Composed of a wide variety of materials, the abrasive materials industry is in the midst of redirection. However, certain segments are fast growing while certain others are at a standstill or, in some cases, declining. Also, there have been new developments in materials, processing and applications in the areas of abrasive materials [2].

A key premise of coating research today is the idea that the coating actually cuts the work-piece, not the substrate body [3]. Among various factors affecting performance and lifetimes of cutting tools, coatings are probably the most important. The coating's composition and adherence qualities are powerful promoters of metalworking productivity.

Controlled variation of substrate materials also enhances coating performance [4]. The substrate must be able to withstand stresses encountered in the cutting operations. For example we have used low alloy steel as substrate, although it shows good adhesion, but it still dull out under cutting stresses.

The use of thermal spray has developed for the past few decades, the basic need for this development has derived from the requirement of high technology applications of surface engineering such as high temperature applications, resistance of wear and corrosion. Furthermore the use of this technology (thermal spray) has been applied even in medical applications [5].

The cutting tool has also been supported by this technology, where the cutting edge hardness increased by coated layer of abrasive materials such as diamond. Currently it's quite difficult to find the related study on this application of thermal sprayed abrasive tool. As a result we hope that this work could widen the ground of thermal spray applications in cutting tool.

The targets of this study are observation of possibilities of using thermal sprayed layers of two different powders, which are Al-Si as soft bonding agent and Ni-Cr-B as hard bonding agent as cutting tools. These layers would be applied to two different substrates, which are low alloy steel and stainless steel.

MATERIALS AND EXPERIMENTAL PROCEDURE.

Two type of powder were used in this study which are [Al-Si (silicon- aluminum) alloy of (50-160 µm) and Ni-Cr-B (nickel-chromium-boron) alloy of (50-160 µm)]. The powder was mixed with 10 Wt% of abrasive materials (diamond), and subsequently used as thermal spray powder.

Thermal spray Metco 5P gun was used and two circular steel discks were used to mask the stainless steel and low alloy steel substrates. The mask allows the coating to take place only on the edge of substrates. The powder was fed from the powder container and heated in the gases stream at high temperature, then directed to the plate to be coated under the gases pressure. The molten and semi molten powder impact on the substrate to form a coating layer.

METALLOGRAPHY AND SEM FOR THERMAL SPRAY COATINGS RESULTS

Figure 1 shows stainless steel cutting wheel coated with Al-Si -diamond. The diamond particles seem strongly knit by bonding powder that was due to lower melting point of Al-Si, Figure 1A

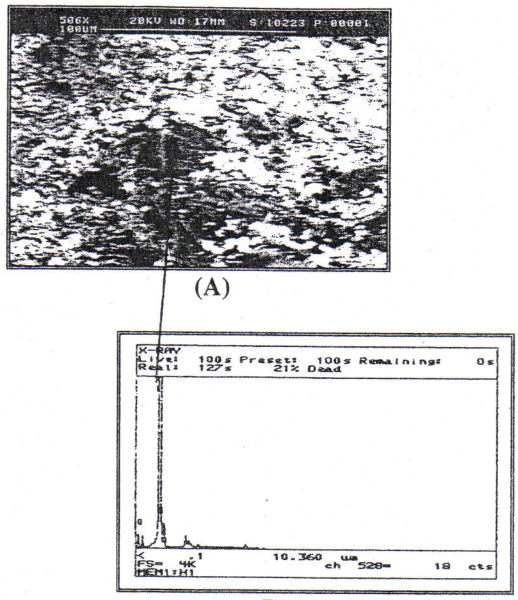


Figure 1 shows stainless steel coated edge area, (C) photograph of coated area , (D) EDX analysis on diamond particles.

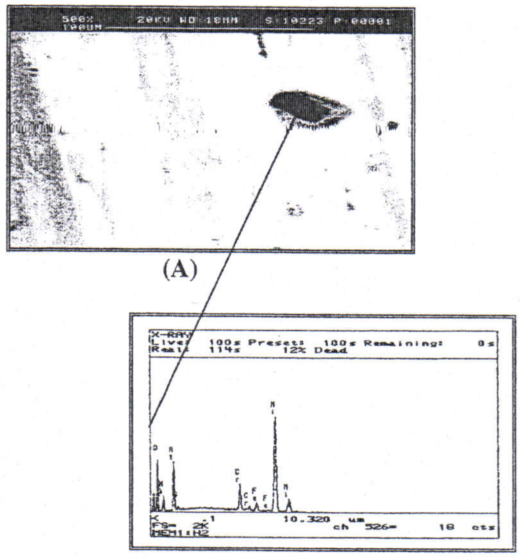
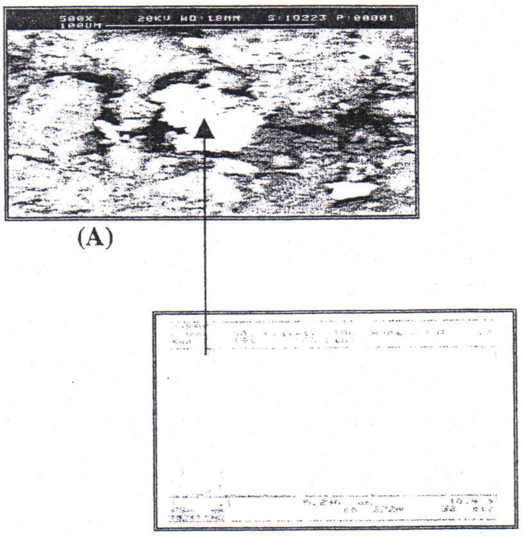


Figure 2 shows cutting edge stainless steel coated with Ni-Cr-B-diamond (A) SEM topography of cutting edge, (B) EDX analysis on Nickel particle.

Figure 2 shows area of wheel cutting edge, whereas in Figure 2 A the black particle according to EDX results could be Ni covered with oxide layer. Figure 3 shows low alloy steel coated with Al-Si-diamond powder, in this figure the splats is more flatten compare to Ni-Cr-B coatings that would help in knitting the coatings particles which in turn gives good retention to the hard abrasive particles.



(A)

(B)

Figure 3 shows mild steel coated with Al-Si-diamond: (A) SEM photograph of coated area, (B) EDX analysis on diamond particle.

WEAR RATE AND DEPTH OF CUT AS FUNCTION OF TIME, CUTTING SPEED AND LOAD.

The wear rate and loss in cutting wheel diameter were plotted versus time at various loads of ,25, 45 and 65 N respectively under constant speed of 6.5 cmsec^{-1} were plotted, figures 4 and 6. Generally, the wear rate increases as the lead increases and reaches maximum value 65 N load. this can be interpreted by referring to the equation used to calculate the wear rate. Adverse relation between contact area and wear rate is shown, as a result of increase of contact area due to deep cutting. This cause the wear rate to decrease according to eq (1).

$$W_R = \Delta W / A_c \qquad (1)$$

Whereas:

W_R is wear rate, ΔW is the loss in wheel weight and A_c :is the contact area.

For further time increment rapid decrease in wear rate was noticed indicating good performance at medium to high load 45 and 65 N. consequently, the depth of cut increases as shown in Figure 5. However, at low load ,25N, wear rate shows different behavior, this may be due to detachment of diamond particles and deposited particles at low load. It was postulated that the position of abrasives might be changed as the load increases [6]. However if the threshold of bond strength is not exceeded, the bonding material will not break. Therefore, abrasives particle stays intact. As a result wear rate decrease and depth of cut increases [6].

In the case of wear of stainless steel cutting wheel coated with Al-Si alloy as bonding agent with diamond as an abrasive. Generally, the wear rate initially increased as the time increased until it reached maximum value depends on operating condition (applied load). this fact is due to wear of coatings on the very sharp edge of the wheel. It appears that the behavior of wear rate at the cutting edge is the similar for all loads. This fact can also be explained as bonding bridge failure [6]. During coating implementation and at the instant of particles impact on the substrate, it is believed that the sputtering of particles is more pronounced at the cutting edge compare with areas on the substrate. Therefore the bonding bridges on the substrate are stronger than bonding bridge at the tip of cutting edges.

As the time and load increase the wear rate decreased due to good adhesion of hard particles toward the plate area inside for medium, 45 N, to high, 65N, load. Referring to Figure 5 increase of depth of cut at the same period was observed.

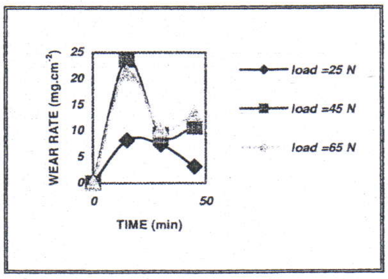


Figure 4 wear rater of stainless steel wheel coated with Al-Si-diamond against time with three different loads and constant 6.5 (cm.sec^{-1})

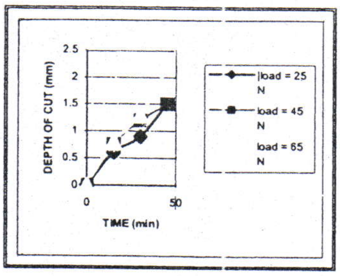


Figure 5 depth of cut of stainless steel wheel coated with Al-Si-diamond against time with three different loads and constant speed (6.5 $cm.sec^{-1}$)

However, the value of wear rate at various load showed reduction in wear rate after 15 minutes as indicated by applying 25 N load. In contrast at 45 N, rapid increase in wheel wear rate occurs as the time increase after 15 minutes. The wear rate, at high load of 65 N, initially increases but lower than that of 45 N. As the time increase at high load of 65 N, the wear rate increased. Due to fatigue bond bridge breaking the wear rate start to increase as the time increase at high load of 65N Figure 4. As soon as the abrasives diamond detached, the friction between the work-piece and wheel can easily increase the wear rate due to soft aluminum properties. This decrease in wear rate accompanied with increase in depth of cut, Figure 5, which means increase in contact area.

Consequently, at speed of cutting, 6.5 $cmsec^{-1}$, the performance showed that at low load the depth of cut is low and the wear rate is low as well. However, at high load ,65N, the depth of cut is high, Figure 5, and the wear rate of cutting wheel is moderate compare with 25 N and 45 N load respectively. With further increase of time the effect of coating appears, as evidence for depth of cut increment.

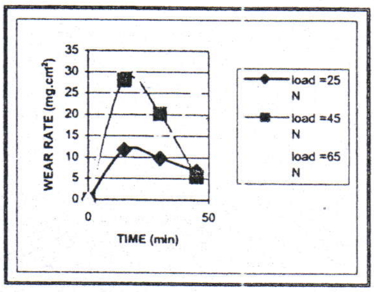


Figure 6 Wear rate of stainless steel wheel coated with Ni-Cr-B-diamond against time with three different loads and constant speed (6.5 $cm.sec^{-1}$)

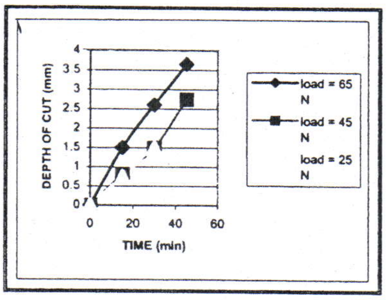


Figure 7 depth of cut of stainless steel wheel coated with Ni-Cr-B-diamond against time with three different loads and constant speed (6.5 $cm.sec^{-1}$)

Figure 6 shows the relation of wear rate against time at 6.5 $cm.sec^{-1}$ with load variation of 25 N, 45 N, 65 N respectively for stainless steel cutting wheel coated with Ni- Cr-B as bonding agent for diamond particles as abrasive. With comparison to the cutting wheel containing diamond bonded with Al-Si alloy Figure 4. Generally, as the time increase the wear rate reaches maximum value then start to decrease again, the main cause explained previously. The significant increase in wear rate at this case probably is due to weak bonding caused by unmelted bonding particles for both bonding bridge which is the main factor of holding abrasives, and inter diffusion reaction between coating and substrate. Furthermore in Ni-Cr-B-diamond coatings rapid increase in wear rate occurs at 30 minutes at 65 N load. However the same behavior occurs at 15 minutes in Al-Si-diamond coating, this shows extreme importance of tool composition [7].

Rapid decrease in wear rate, Figure 6, is due to a better bonding toward the inside area of the cutting wheel. Figure 7 shows the increase in depth of cut as wear rate decreases. Referring to Figure 5 which has undergone the same operating condition of Figure 7, the performance of the Ni-Cr-B coated cutting wheel is much better than that of Al-Si. This fact shows the importance of bonding agent.

Comparing two different coatings, Figure 4 and 7, at same operating conditions show significant different in wear rate. Wear rate of Ni-Cr- B is higher than that of Al-Si. However, the Al-Si alloy softer than the Ni-C-B. Ai-Si alloy can achieve good melting, and high impact velocity. The importance of inter diffusion reaction comes at the same level, which is between coating and substrate.

CONCLUSION.

Thermal spray process can be used not only in surface treatment, however it can be used in producing cutting wheel as well. This process performs effectively when the used substrate and powder is properly chosen. Besides, the possibility of adhesion between substrate and coating can be enhanced by further heat treatment with respect to oxidation.

At load and speed 25 N, 6.5 $cm.sec^{-1}$ respectively, the Ni-Cr-B-diamond coated wheel has better performance, where it showed better rate of depth of cut ,1.3$\mu m.sec^{-1}$, with lower wear rate compare with Al-Si-diamond coated wheel.. At 45 N the Ni-Cr-B-diamond coated wheel still show good performance where the rate of depth of cut is 1$\mu m.sec^{-1}$ with low wear rate. At 65 N the Al-Si-diamond coated wheel shows better performance where the rate of depth of cut is 0.85 $\mu m.sec^{-1}$ with lower wear rate than the other wheels tested under the same conditions.

ACKNOWLEDGEMENT.

The authors gratefully acknowledge the school of materials &mineral resources engineering USM for the support for this work.

REFERENCES

1-http://www.abrasiv.ru/en/index.html (April-2001)

2- Edward M. Trent, (2000). Metal cutting.Butterworth-Heinemann

3-J. L. Metzger, MSc, PhD, (1986). Superabrasive Grinding, Butterworths

4-E. Lang, Coatings For High Temperature Applications,

5-K. N. Strafford & P. K. Datta & J. S. Gray. (1990) Surface Engineering practice, process, fundamentals and applications in corrosion and wear. ELLIS HORWOOD.

6-Jozef A. Borkowski & Andrzej M. Szymanski & T. R. A. Pearce. (1992). Uses of Abrasives and Abrasive Tools. Ellis Horwood.

7.http://www.idrmag.com/idr575/noframes.htm#fig10 (April-2001)