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Abrasive Wear Characterization for Different Grades of Tungsten Carbide Material

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Abstract— ***A present study has been conducted on the tribological properties of different grades of tungsten carbide material by carrying out an abrasive wear test using ASTM G65. The composition of different grades of tungsten carbide was varied and binder content ranged from 6 to 20Wt%. Five graded compositions were studied which includes cobalt binder and alloy binder. Abrasive wear was investigated by conducting three body abrasive wear test, so that we can rank the material inturn we can select the best grade for real time application like wire drawing process. There are many test procedures available for abrasion wear. Not much work has been carried out in comparing the results of these procedures. Real time applications like Wire Drawing are much more complex in terms of abrasion wear compared to a standard test. This work is an attempt to study the relation between the standard test and real time application like wire drawing process for five different grades like Grade-A, Grade-B, Grade-C, Grade-D and Grade-E which vary by binder percentage and grain size.***

Keywords: ASTM G65 (Three Body Abrasive Test), Tungsten Carbide, Cobalt, binder, Wire Drawing Process

I. Introduction

Tungsten carbide (WC) has been well known for its exceptional hardness and wear/erosion resistance. Matrices of ductile metals, such as cobalt, greatly improve its toughness so that brittle fracture can be avoided. Cemented tungsten carbides are commercially one of the oldest and most successful powder metallurgy products. These composites are essentially aggregates of particles of tungsten carbide bonded with cobalt metal via liquid-phase sintering. The properties of these materials are derived from those of the constituents – namely, the hard and brittle carbide and the softer, more ductile binder. The role of cobalt in cemented carbides is to provide a ductile bonding matrix for tungsten carbide particles. Cobalt is used as a bonding matrix because its wetting or capillary action during liquid phase sintering allows the achievement of high densities. In its most basic form, tungsten carbide is a fine gray powder, but it can be pressed and formed into shapes for use in industrial machinery, cutting tools, abrasives, other tools and instruments.

In wire drawing process the cross section is reduced by the pulling it through a conical die which is inserted in the die box and the wire is pulled by cylindrical drum which is run by electric motor.

Wear is defined as the progressive loss of material from the surface of a solid body due to mechanical action, i.e. the contact and relative motion of a body against a solid, liquid or gaseous counterbody. There are many different mechanisms of wear that contribute to the wear down of mechanical components in relative motion of contacting surfaces. The wear mechanisms can be divided into adhesive, abrasive and erosive wear depending on the type of contact is as shown in Fig.1 [1]. Adhesive wear gives surfaces with periodic wear patterns. In abrasive wear, hard particles or material asperities scratch one of the surfaces. The particles or asperities are called abrasives and they carry at least some of the load between the two surfaces. If the abrasives are fixed to one of the surfaces and cause scratching of the other surface the wear mechanism is called two body abrasion. This situation gives striped surfaces with a lot of parallel scratches. In three-body abrasion the abrasives are loose and free to slide and roll between the surfaces. The wear pattern is usually more irregular with many pits. A common phenomenon is when the abrasives are embedded into the softer surface and later cause two-body abrasion on the harder surface. Erosive wear involves hard particles or liquid droplets, transported by a flow of liquid or gas, which hit the surface and cause wear [2]. The consequence on the surface depends on the kinetic energy of the particles or droplets; often many hits are needed to cause wear.

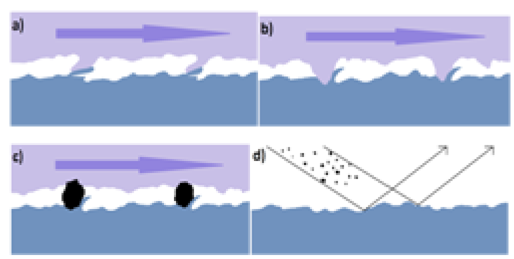

Figure 1 a) adhesive wear, b)two-body abrasion, c) three-body abrasion and d) erosion

In this paper, abrasion wear testing have been presented to rank the best grade of tungsten carbide material by conducting three body abrasion test and correlate the relation between the standard test and real time application like steel wire drawing process.

II. Three Body Abrasive Wear Test

Different grades named as Grade-A, Grade-B, Grade-C, Grade-D and Grade-E whose composition and carbide grain size is shown in Table-1

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Table-1 Composition of Different Grades

Grade Name	Binder content (wt%)	Binder Type	Carbide Grain Size (μm)
Grade-A	6%	Co	1.0 – 1.2
Grade-B	12%	Co	2.0 – 3.0
Grade-C	15%	Co	2.0 – 3.0
Grade-D	15%	Co+Ni+Cr	4.0 – 7.0
Grade-E	20%	Co+Ni+Cr	4.0 – 7.0

III. Testing of Samples by ASTM G65

Abrasive wear testing was conducted at room temperature on a three-body abrasive wheel. The schematic representation of steel wheel test set up is as shown in Fig.3.4.In the present study, Quartz silica sand with a grain size of 250 μm is used as the abrasive. The abrasive particles of Quartz silica sand were irregular in shape with sharp edges is as shown in fig.3.5. The abrasive was fed at the contacting face between the rotating steel wheel and the test sample. The tests were conducted at a rotational speed of 200 rpm. The rate of feeding the abrasive is 350 g/min. Its initial weight was determined in a high precision digital balance before it was mounted in the sample holder. The abrasives were introduced between the test specimen and rotating abrasive wheel composed of steel wheel (hardness 40) and chlorobutyl rubber tyre (hardness: A 60). The diameter of the steel wheel used was228 mm. The test sample was pressed against the rotating wheel at a specified force by means of lever arm while a controlled flow of abrasives abrades the test surface. The rotation of the abrasive wheel was such that its contacting face moves in the direction of sand flow. The pivot axis of the lever arm lies within a plane, which was approximately tangent to the steel wheel surface and normal to the horizontal diameter along which the load was applied. At the end of test duration, the sample was removed, thoroughly cleaned and again weighed (final weight). The difference in weight before and after abrasion was determined. At least three tests were performed and the average values so obtained were used in this study. The experiments were carried out for load of 150N at a constant sliding distance of 8591.4m. The wear was measured by the loss in weight, which was then converted the volume loss of the sample as per formula shown in equation (1).

$$Volume\ loss\ [mm3] = \frac{mass\ loss\ [g]}{density\ \left[\frac{g}{cm3}\right]} X\ 1000 \qquad (1)$$

VI. Results and Discussion

The weight values measure before and after the test as well as the volume loss is as shown in the table 2 which is shown in appendix.

After testing of three body abrasive test, wear structure is as shown in the Figure 2.

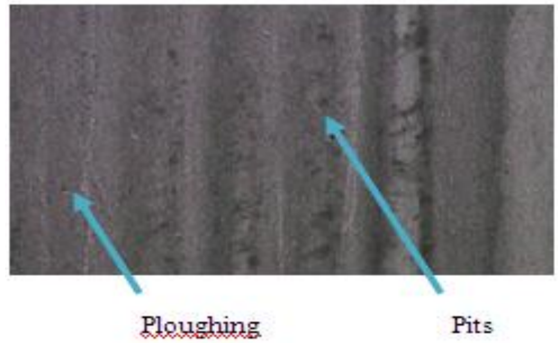

Figure 2 Microstructure of Grade-A after Three Body Abrasive Test

Microploughs are not observed in a few test samples which can be attributed to homogeneous mixing of powder during manufacturing of samples. But few sample surfaces of same grade contain ploughs which could be the source point for further failure modes like cracks, wear debris etc. which cause material removal and increase the wear rate because of plastic deformation. This becomes more important than microcutting action.

A. Wear Patterns on Different Wire Drawing Dies

Initial weight and final weight of different grade wire drawn pellets have been noted and then each pellet is wire cut into half and wear pattern is captured by using microscope is as shown in Figure 3. From this we can calculate the weight loss and suggest the best grade for Wire Drawing Application. Difference between initial and final weights are as shown in table 3.

Figure 3 Wear Pattern Dies

Table - 3 Difference in Weight

Grade specification	Initial weight (g)	Final Weight (g)	Difference (g)
Grade-D	19.0046	18.8102	0.1944
Grade-A	18.6649	18.5815	0.0834
Grade-B	18.3936	18.269	0.1246
Grade-B	18.8441	18.653	0.1911

B. *Depth of Abrasion of Each Grade after Three Body Abrasion Testing*

By calculating the depth of abrasion, we can conclude that the wear resistance ranges in the descending order as follows: Grade-A, Grade-B, Grade-C, Grade-D and Grade-E. Depth of abrasion of different grades is listed in the table 4 which is shown in appendix.

C. *Failure Mode Effect Analysis*

All the failure modes have been addressed.
Abrasion wear was found to be the most critical parameter for die failure.
The best grade for the considered application (Wire Drawing) is found to be Grade-A
Die life has been achieved to customer requirement by varying the die geometry

FMEA results are shown in table 5 which is shown in appendix.

VII. Conclusion

A. *The most important findings of the three body abrasive test are*

Wear resistance test according to ASTM G65 standards shows, Grade– A has the best abrasion resistance. Wear resistance of this sample is 1.63 times higher than typical Grade – E sample.

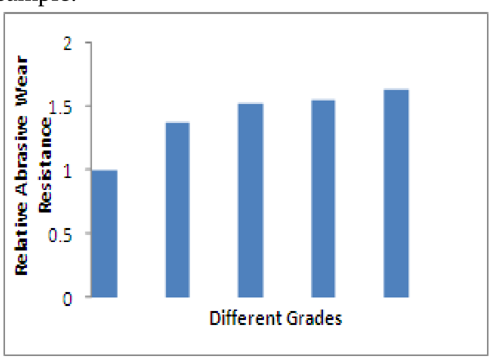

Figure 4 Graph of Different Grades versus Relative Abrasive Wear Resistance

By observing the depth of abrasion on samples after three body abrasion test, Grade – A has a minimum depth of 0.34mm compared with other grades.

Also by calculation, Wear number and Wear Resistance is higher in Grade – A, hence we can suggest that Grade – A is hardest in comparison with other grades by three body abrasion testing.

B. *The most important findings in wire drawing pellets are;*

By measuring the initial and final weight of each wire draw pellets of different grades we observed that Grade-A has minimum weight loss of 0.0834g in comparison with other grades and hence we can suggest that Grade-A has higher abrasion resistance.

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APPENDIX

Table - 4 Depth of abrasion of Each Grade after Three Body Abrasion Testing

Sample Designation	Depth of Abrasion in mm			Maximum Depth (mm)	Average Depth (mm)
	1	2	3		
Grade – A(1)	0.35	0.36	0.36	0.36	0.34
Grade – A(2)	0.26	0.29	0.32	0.32	
Grade – A(3)	0.32	0.33	0.34	0.34	
Grade – B(1)	0.43	0.46	0.47	0.47	0.43
Grade – B(2)	0.42	0.43	0.43	0.43	
Grade – B(3)	0.38	0.37	0.39	0.39	
Grade – C(1)	0.63	0.68	0.65	0.68	0.66
Grade – C(2)	0.65	0.65	0.60	0.65	
Grade – C(3)	0.66	0.69	0.61	0.65	

Grade – D(1)	0.71	0.69	0.70	0.71	0.6933
Grade – D(2)	0.62	0.61	0.62	0.62	
Grade – D(3)	0.73	0.75	0.74	0.75	
Grade – E(1)	0.77	0.76	0.77	0.77	0.7633
Grade – E(2)	0.75	0.75	0.74	0.75	
Grade – E(3)	0.77	0.76	0.77	0.77	

Table - 5 Potential Failure Mode & Effect Analysis

Product	Product requirement	Potential failure mode	Potential effect (s) of failure	Severity	Potential cause (s) / Mechanism of failure	Occurrence	Current Controls	Detection	RPN	Recommended action	Responsibility	Target Completion Date	Action results				
													Actions taken	Severity	Occurrence	Detection	RPN
Wire Draw Pellet	7.5 Tonnes of wire to be drawn	Poor finish on die profile	Wire quality deterioration	7	Die geometry is not suitable	8	Designer control based on application inputs	3	216	Revisit the design	Kelvin	23-04-2014	Die geometry has been modified to suit the customer requirement	9	2	2	36
	Good surface finish on the drawn wire		Premature die failure	9	Not well lubricated	3	Die is immersed in the coolant bath during drawing operation.	3	81								
	Tolerance on the drawn wire to be maintained within +10 to +30 microns				Die grade not suitable	8	Designer control based on application inputs	3	216	Revisit the design	Kelvin	23-04-2014	Grade selected based on customer report and with attending the trails	9	3	3	81
					Usage of old coolant/lubricant	7	Used production machines during trial	5	315	Suggest plant people to change the lubricant frequently.	Navya	22-04-2014	Proper training had given to plant people for maintenance of machine				
					Machine works Unsteadily	5	Machine maintenance will be carried once in a week.	3	135								
					Wire has undulations Speed	5	Has standard set wire speed for the drawing operation.	3	135								
					Straightening rollers not correctly set	5	Set the rollers correctly balanced	4	180								
					Abrassive wear on the pellet geometry.	8	Used Lubicants for the operation	4	288	Selecte the proper materail grade, Polish the pellet geometry, Avoid using old or used lubricants.	Navya	23-04-2014	In line with operation proposed different grade, suggested customer to not ot use old lubricants.	9	4	3	108
					Wire snaps during the drawing process.	6	Speed will be set as per the process	4	216	Check for mismatch with wire collector and check for the proper set speed while trall.	Kelvin	23-04-2014	Maintained uniform speed at the wire collector to avoid snapping of wire drawn	9	4	3	108
		Bore enlargement due to wear	Delay in production	9	High reduction percentage	4	Increase number of reduction stages	2	72								
					Die OD taper does not match holder	8	OD and taper ground to suit the holder	3	216	Measure the present holder and made the changes in our pellet outer design.	Navya	24-04-2014	Requested customer to provide the existing tool holder and made changes in our pellet to assemble with holder, Parts are inspected before dispatch.	9	5	2	90
					Die geometry is not polished well	7	Inspected before dispatch	5	315	Revisit the design and study the application.	Kelvin	23-04-2014	Present polish method is well suited to the operation and achieving required surface finish on the pellet geometry. Parts are inspected before dispatch.	9	5	3	135
					Ovality might occur during the operation owing to rotating type of holder	3	Assembly of the wire stands inspected before loading	4	108								
					Jaws do not have appropriate configuration	4	Rewind slightly the jaws and rollers	4	144								
							TOTAL RPN		2637								558

Table - 2 Test Results after Three Body Abrasive Wear Test

Specimen designation	Weight before test (g)	Weight after test (g)	Weight loss (g)	Volume loss (mm^3)	Avg. Volume loss (mm^3)	Relative abrasive wear resistance	Specific Wear rate $mm^3/N.m$	Wear resistance $N.m/mm^3$
Grade-A(1)	120.1201	119.2376	0.8825	59.2281	58.4451	1	0.00000435	22048.999
Grade-A(2)	121.0132	120.1610	0.8522	57.1946				
Grade-A(3)	121.1461	120.2683	0.8778	58.9127				
Grade-B(1)	113.7546	112.8614	0.8932	62.4615	61.4825	1.052	0.00000477	20959.720
Grade-B(2)	116.5684	115.6812	0.8872	62.0419				
Grade–B(3)	116.0984	115.2412	0.8572	59.9440				
Grade-C(1)	114.0211	112.9268	1.0943	78.1642	69.8809	1.195	0.00000542	18440.747
Grade-C(2)	114.0213	113.1210	0.9003	64.3071				
Grade-C(3)	113.7554	112.8150	0.9404	67.1714				
Grade-D(1)	113.9814	112.9916	0.9898	70.7	73.5547	1.258	0.00000571	17519.696
Grade-D(2)	111.9817	110.9189	1.0628	75.9142				
Grade-D(3)	112.9879	111.9512	1.0367	74.05				
Grade-E(1)	106.9915	105.9910	1.0005	74.1111	75.6987	1.295	0.00000585	17023.489
Grade-E(2)	107.9954	106.9421	1.0533	78.0222				
Grade-E(3)	105.9888	104.9768	1.0120	74.9629				