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ANALYSIS OF FAILED STRATAPAX® - STEEL STUD CUTTER ELEMENTS

L. E. Pope

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ANALYSIS OF FAILED STRATAPAX® - STEEL STUD CUTTER ELEMENTS

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ABSTRACT

Stratapax-steel stud bond strengths were evaluated in a quality control test fixture at loads up to 410 MPa. No failures occurred for cutter elements bonded in the first six diffusion bond runs. In the next two bond runs, Stratapax-steel stud cutter elements failed at test loads significantly less than 410 MPa. A failure analysis was performed on several of the failed cutter elements to isolate the material weakness responsible for the low load failures. Three groups of failures were identified: a cobalt depletion region on and immediately beneath the cemented carbide surface of the "as-received" Stratapax blanks, surface contamination at the carbide-steel bond joint and a weakness within the steel stud near the bond joint. Two additional defects were observed which were of some concern, namely, lamination line defects within the carbide portion of Stratapax blanks and severe grind damage on carbide surfaces of "as-received" Stratapax blanks. It was recommended that a grind schedule be included as part of the specimen preparation prior to bonding to alleviate the observed failures.

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ANALYSIS OF FAILED STRATAPAX® - STEEL STUD CUTTER ELEMENTS

Introduction

During the past several years, considerable experimental effort has been expended to identify applications for the bi-material Compax®, which is a thin, dense and sintered polycrystalline aggregate of manufactured diamonds on a cemented tungsten carbide substrate.¹ The diamond compact has abrasion and wear resistant properties approaching that of a natural diamond, but because of the random crystal orientation, it doesn't have the directional wear properties and susceptibility to fracture on impact which natural diamonds have. Initially, experimentation was limited to single-point turning in machining operations in hopes of replacing expensive single-point, single-crystal diamond cutters. These experiments led to the obvious extension of diamond compact cutters to rotary drag bit applications where each cutter on a bit performs in a designed interrelated manner but yet similar to a single-point cutter.

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Sandia National Laboratories has evaluated gas pressure bonding of Stratapax* blanks to carbide and steel studs.² The primary motivation for substituting steel studs for the previously used carbide studs was toughness. Many failures of Stratapax cutters in drilling applications were due to fracture of the carbide stud. A second reason was that the use of steel studs permits the replacement (repair) of a defective Stratapax cutter element in the field in less than one hour. The first six gas pressure bond runs were very successful in that an excellent bond joint was formed between the Stratapax blank and the steel stud. More than twenty cutter elements were selected randomly from these runs and were loaded in a quality control test fixture up to 410 MPa without a single bond failure. The test fixture was designed to load the bond joint primarily in shear. Within the subsequent two bonding runs, some samples failed at loads significantly less than this minimum strength value.

To insure a high degree of reliability in drag bits using Stratapax cutters, it was necessary to identify and eliminate the causes of these low failure loads. Typical specimens were selected from the failed cutter elements and diagnostic evaluations were performed to identify the material weakness which caused the low failure loads. Within this paper we report the results of our diagnostic evaluations of Stratapax cutter elements which failed at loads below 410 MPa. A brief summary of

*A Stratapax is a Compax where the composition of the cemented carbide is modified to make the Compax more suitable for drag bit drilling.

the development of Stratapax cutters is presented first to put this study in proper perspective relative to other published work. The pertinent background information of the specimens examined in this study is also presented prior to the specific results. Each failure type is presented and discussed as a separate topic. A recommended procedure to eliminate these failures in future Stratapax-stud cutter elements is presented.

Development of Stratapax Cutters

Continuous and interrupted single-point machining studies with Compax and Stratapax cutters³⁻⁶ basically have shown that the diamond cutters have sufficient strength, toughness and hardness to withstand the severe stress and abrasive conditions required for machining rocks. Machining results were used to assist in design of rotary Stratapax (Compax) drag bits for oil well drilling.

In early oilfield testing of the Compax,⁷ the Compax was brazed to a carbide stud which was mounted on the bit body. These tests were encouraging for soft to medium-hard rock formations, but either design and/or material deficiencies precluded the drilling of very hard and fractured formations. Two types of failure were noted. Diamond cutting elements were lost due to failure of the braze joint and by fracture of the cemented carbide stud. Modifications in the brazing technique resulted in successful drilling of soft shale formations which had hard

rock inclusions.⁸ Later drilling tests in medium formations showed good potential for low bit weights.⁹ Again, in these tests, the principle diamond cutter failure modes were loss of the Stratapax at the braze joint and fracture of the cemented carbide stud.

Early bond joints between diamond cutters and carbide studs were made with a conventional low temperature braze. For this braze, Stratapax bond failures were shown to be more dependent on braze erosion and softening due to friction generated temperature during cutting than on the room temperature shear strength.⁴ The expected room temperature shear strength was nominally 240 MPa. Changes in the brazing procedure have produced significant improvements in the integrity of the braze joint, but it is not yet known if these improvements are sufficient for all applications. Room temperature shear strengths approaching 500 MPa are now possible, which is strong enough if friction generated softening does not occur. Drilling tests will resolve this uncertainty.

In a parallel program, gas pressure diffusion bonding was evaluated as an alternate approach to brazing for bonding Stratapax diamond cutters to studs.¹⁰ Diffusion bonding was, and is, attractive because of potential high joint efficiencies and controllable thin bond joints. Room temperature shear strengths of 500 MPa have been measured for diffusion bonds of Stratapax blanks to carbide studs.¹¹ These values are approximately twice that of conventional low temperature braze joints and slightly exceed that of the recently developed higher

temperature braze joints. The diffusion bonds have the added advantage of being less susceptible to friction generated temperature; softening occurs at higher temperatures. Efforts are now in progress to transfer the gas pressure diffusion bonding process to commercial suppliers.^{11,12}

As was pointed out previously, the second major difficulty encountered in using Stratapax diamond cutters for rotary drag bit drilling was fracture of the carbide stud. The initial and most obvious approach to solve this difficulty was to more properly select the composition of the cemented carbide stud. Though hard to isolate, there is little doubt that this resulted in less breakage. Recently Sandia National Laboratories initiated a program to substitute steel studs for the previously used carbide studs,² and some excellent bonds between the Stratapax and the steel stud have been produced. Insufficient field tests have been completed to conclude whether or not the Stratapax-steel stud combination eliminates stud breakage during drilling. Breakage of the steel stud has not yet been observed.

Background of Failed Cutters

The integrity of gas pressure diffusion bond joints between Stratapax blanks and steel studs was tested by loading to 410 MPa in a quality control test fixture which loaded the bond joint primarily in shear. Within the first six bond runs, more than twenty specimens were tested with no failures. Within the

next two runs, labeled "H" and "L," failures occurred at stresses significantly less than 410 MPa. The failure loads of the specimens on which diagnostic evaluations were performed are listed in Table I. "As-received" Stratapax blanks were examined also.

TABLE I
Measured Failure Loads of
Stratapax-Steel Stud Cutter Elements

<u>Sample Number</u>	<u>Group</u>	<u>Ultrasonics</u>	<u>Failure Load (MPa)</u>
L20-3	A	Bad	0
L31-1	A	Good	163
L10-3	B	Good	359
L14-2	B	Good	310
L15-1	B	Good	330
L3-3	C	Good	306
L4-2	C	Good	412
L21-4	C	Good	289
H12-1	-	Good	215

The "H" run was a standard run with no metallizing layer duplicating the previous six successful bonding runs. The quality control report after solvent cleaning and after hydrogen firing noted that most of the carbide surfaces were dark in color. This was contrasted with the typical metallic appearance in previous runs. It was also noted that at 100X magnification, more severe grind damage was present on the carbide surfaces than for previous bond runs. The "L" run incorporated three different specimen preparation procedures just prior to encapsulation in the pressure transmitting medium. No special quality control notes

were recorded. Group A consisted of Stratapax blanks which were solvent cleaned and wire brushed, Group B consisted of Stratapax blanks which were solvent cleaned and RF sputter cleaned in argon, and Group C consisted of Stratapax blanks which were prepared identical to Group B except a sputtered nickel metallizing layer was deposited. In all three groups, the 4340 steel studs were wire brushed just before encapsulation in the pressure transmitting medium.

The diagnostic techniques used were standard scanning electron microscopy (SEM), Auger electron spectroscopy, x-ray diffraction, metallography and elemental analysis by x-ray fluorescence in a SEM.

Failure of Stratapax Carbide, Group A

One of the most surprising results obtained in bonding Stratapax blanks to 4340 steel studs was that of L20-3 (see Table I) where essentially zero shear stress was required to separate the Stratapax from the stud. Typical SEM photomicrographs of the failure fracture surfaces are shown in Figure 1. The same features are present on both fracture surfaces, namely, a distribution of tungsten carbide particles. Hence, the fracture occurred within the cemented carbide portion of the Stratapax and a bond with some integrity had been formed. Similar features were observed for L31-1.

(a)

(b)

Figure 1. Failure fracture surfaces of L20-3 in Group A.
(a) Stratapax side, (b) stud side. (5000X).

It was also indicated in Table I that the measured ultrasonics for L20-3 were bad. This terminology was meant to imply that extensive dispersion of the ultrasonic signal had occurred. Sizable defects, probably cracks, must have been present prior to loading. Since failure occurred at zero load, the cracks essentially covered the entire cross section of the part. The mechanical handling required to wire brush and encapsulate the parts prior to the bond run precludes the possibility that the cracks existed to that magnitude prior to bonding. Furthermore, the bond run would tend to heal cracks until the cooling sequence was initiated where thermal stresses became significant. We

conclude, therefore, that the size and/or number of defects (cracks?) were amplified by thermal stresses during cooling in the gas pressure bond run.

Cemented tungsten carbide cermets are a dispersion of tungsten carbide particles in metallic binder which is typically cobalt. The continuous cobalt phase coats the tungsten carbide particles and is nominally one or two tenths of a micron thick between adjacent tungsten carbide particles. During the fracture process, the cobalt fails in a ductile manner. The morphology of typical cemented tungsten carbide fracture surfaces is shown in Figure 2, where a distribution of tungsten carbide particles and a superimposed network of light hair-like lines (failed cobalt binder) are observed.

Figure 2. Typical tungsten carbide fracture surface. (5000X).

It is obvious that much less ductile fracture occurred in sample L20-3 than in the typical example depicted in Figure 2, and this explains the low failure load. Either there was insufficient cobalt present or the cobalt which was present was chemically bound in a brittle phase like eta phase ($\text{Co}_3\text{W}_3\text{C}$).

To detect the presence of eta phase, an x-ray diffraction analysis was performed on both sides of the fracture surface of L20-3 and on "as-received" Stratapax blanks. Diffraction peaks from tungsten carbide and cubic cobalt were detected. No evidence was found of any other crystalline compound, specifically eta phase. Since the presence of 2 wt.% eta phase within the top few microns beneath the fracture surface is detectable, and since the fracture process highlights cobalt locations where eta phase would exist, it is concluded that at most a negligible amount of eta phase was present.

To verify that little or no cobalt was present on the fracture surface, elemental analysis using energy dispersive x-ray fluorescence in a SEM was performed. Both failure fracture surfaces and fractured surfaces of "as-received" Stratapax blanks were examined. Results are listed in Table II. There is a dramatic difference in the cobalt level for the two specimens examined from Group A in comparison with typical "as-received" controls--only trace amounts of cobalt were present at the failure fracture surfaces. Fracture occurred, therefore, in a cobalt depleted region of the carbide portion of the Stratapax.

TABLE II
Tungsten and Cobalt Elemental Analysis
on Fractured Surfaces

<u>Identification</u>	<u>Arbitrary Intensity Units</u>		<u>Cobalt/Tungsten Ratio</u>
	<u>Cobalt</u>	<u>Tungsten</u>	
"As-received" #1	57	100	0.57
"As-received" #2	57	104	0.55
"As-received" #3	66	98	0.66
L20-3	6	73	0.08
L31-1	4	104	0.04

To characterize the spatial relationship between the fracture plane and the bond joint, a perpendicular metallographic section was prepared on the stud side of the fracture. A typical area is shown in Figure 3. The distance between the bond joint and the fracture plane is essentially constant and is about six microns. Thus, the gas pressure diffusion bond was successfully made, and its strength exceeded that of the cobalt depleted carbide.

Figure 3. Section perpendicular to the fracture plane of L20-3 on the stud-side. (1000X).

To define the thickness of the cobalt depleted region, the L20-3 Stratapax was fractured perpendicular to the original fracture plane, and the morphology of this fracture plane was examined in a SEM. The presence or absence of cobalt failure was specifically looked for. In Figure 4a, a low magnification photomicrograph is shown. Parallel to the original fracture surface and at a nominal depth of twenty-five microns, a demarcation feature is readily apparent. Arrows identify the feature referred to. Figures 4b and 4c are photomicrographs which include the demarcation feature, again identified by arrows, but which emphasize the region above and below the demarcation feature, respectively. Figure 4d is a photomicrograph of the interior. Those regions above the demarcation feature show a fracture morphology with no evidence of ductile cobalt failure similar to the failure fracture surfaces (see Figure 1), while those regions below the demarcation line show a fracture morphology with characteristic ductile cobalt failure (see Figure 2). This analysis was repeated at several locations with the same results. Hence, it is concluded that the thickness of the cobalt depleted region was thirty microns, twenty-five microns below and five microns above the fracture plane. The demarcation feature defines the transition between interior-like tungsten carbide-cobalt and the cobalt depleted cemented carbide. The location of the fracture plane was probably controlled by thermally generated stresses on cooling due to differences in thermal expansion coefficients of steel and cemented carbides. In the case of L20-3, cracks were probably initiated and

(a)

(b)

(c)

(d)

Figure 4. A depth profile beneath the fracture plane of L20-3. (a) demarcation feature identified (1000X), (b) area just above demarcation feature (5000X), (c) area just below demarcation feature (5000X), (d) typical interior area (5000x).

propagated on the failure plane during the cooling sequence of the bond run.

Low Bond Strengths, Groups B and C

All of the cutter elements on which diagnostics examinations were performed in Groups B and C failed at applied loads in the range of 290-410 MPa. Specific loads for failure were listed in Table I. SEM photomicrographs of failure fracture surfaces are shown in Figure 5, and SEM photomicrographs of fracture surfaces perpendicular to the failure fracture planes are shown in Figure 6. An examination of Figures 5a and 6a, Group B, indicated for the areas depicted here that failure occurred primarily in the 4340 steel but near the steel-carbide interface. This was inferred from the evidence of ductile shear failure seen in the photomicrographs. A small percentage of the fracture occurred at the carbide-steel interface as evidenced by carbide grains on the fracture surface (see the top left corner of Figure 5a). SEM elemental analysis using energy dispersive x-ray fluorescence showed that the area illustrated in Figure 5a was representative of the failure surface. Mostly iron and little tungsten were found; specific results are listed in Table III.

An examination of Figures 5b and 6b, Group C, indicated that fracture occurred in a ductile shear failure mode near the steel-nickel bond surface. SEM elemental x-ray fluorescence

(a)

(b)

Figure 5. Failure fracture surfaces. (a) L10-3, Group B, (b) L4-2, Group C (5000X).

(a)

(b)

Figure 6. Fracture surface perpendicular to the failure fracture plane. (a) L10-3, Group B, (b) L4-2, Group C (5000X).

TABLE III
Elemental Analysis on the Stratapax Side
of Failure Fracture Surfaces*

<u>Random Areas</u>	<u>Arbitrary Intensity Units</u>					
	<u>L10-3, Group B</u>			<u>L4-2, Group C</u>		
	<u>Fe</u>	<u>W</u>	<u>Fe/W</u>	<u>Fe</u>	<u>Ni</u>	<u>Ni/Fe</u>
1	100	12	0.12	100	92	0.92
2	122	11	0.09	122	101	0.83
3	109	10	0.09	101	89	0.88
4	107	12	0.11	125	102	0.74
5	-	-	-	113	94	0.83
Ave.	110	11	0.10	112	94	0.84

*Only major elements are listed in the table. Trace amounts of Co, Cr and Mn were found in L10-3. Trace amounts of Cr and Mn were found in L4-2, but W and Co were not found.

analysis showed that the area illustrated in Figure 6a was representative of the failure surface. Only iron and nickel were detected with the iron consistently having the higher intensity (see Table III). Hence, failure occurred on the steel side of the steel-nickel bond surface with a significant percentage of the failure occurring at or on the nickel side of the bond joint.

It was encouraging for both Group B and Group C that a sharp interface existed between the cemented carbide and the material to which it was bonded. No evidence was found of severe carbide grind damage nor of surface contamination; both of which were found on other samples and will be discussed subsequently in this paper.

It was concluded that the carbide portion of the Stratapax had typical properties and was properly prepared for bonding. The cemented carbide was not the cause of the lower than expected failure loads. The low failure loads were apparently a result of material weakness within the steel for both Group B and Group C. The specific source of the weakness was not found, but contamination at the bond joint which diffused into the steel during the bond run is most suspect.¹³

Carbide Surface Contamination and Grind Damage, H12-1

Within gas pressure bond run "H," most of the tested cutter elements failed at a load stress of approximately 200 MPa. Specimen H12-1 was selected as being typical of the lot and diagnostic examinations were made. Initially, an examination was made of a fracture surface perpendicular to the bond joint. Cobalt depletion was looked for but was not found. A random distribution of foreign material at and extending a few microns beneath the failure fracture plane was found. A SEM photomicrograph of a typical contamination area is shown in Figure 7a. Some insight into the source of this contamination was gained by using Auger electron spectroscopy coupled with depth profiling on the failure fracture surface. The contaminant elements detected on and immediately beneath the failure fracture plane were Al, Si, O and trace amounts of Ca, Mg, Ni and N; none of

(a)

(b)

Figure 7. Failure fracture plane of H12-1. (a) contamination, (b) lamination defects. (1000X).

these elements were detected within the bulk carbide. The structure of the Al and Si indicated that they were present as oxides, probably Al_2O_3 and SiO_2 . Since the contaminant elements were present only within a few microns of the failure fracture surface, essentially the original grind surface, it is reasonable to presume that they were introduced during surface preparation of the carbide and/or the steel stud prior to the gas pressure bond run. It has been pointed out in the literature¹³ that the presence of contaminants at the bond joint can seriously degrade the strength of the bond.

A second feature was observed on the fracture surface perpendicular to the bond joint. Straight line defects parallel

with the bond joint (the carbide grind surface) existed at two depths, approximately twenty-five and forty-five microns below the fracture plane. An area illustrating both line defects, marked by arrows, is shown in Figure 7b. The regularity and straightness of these defects seems to preclude the explanation that they were produced during the fracture process. Many fracture surfaces in cemented carbides were examined in this program and in other programs without observing such features. A material defect must have existed which the fracture process highlighted. Examination at higher magnification in a SEM indicated that a metallurgical bond existed across the linear defects which suggests that the defects were formed and subsequently healed.

Classical powder metallurgy procedures were used to prepare the cemented carbide portion of the Stratapax. Improper lubrication and/or incorrect pressing parameters can result in pressing laminations. Pressure assisted densification can heal this type of lamination without removing the evidence of the lamination. Since the cemented carbide was densified simultaneously with the pressure-temperature bonding of the man-made diamonds to each other and to the cemented carbide substrate,¹ the observed linear defects could have been formed in that manner. Some other process may be responsible for the laminations. It is not possible, however, that the laminations were formed after the gas pressure diffusion bond run because temperature and pressure are required to form metallurgical bonds across laminations.

Even though the linear defects exhibited a strength greater than the failure load, it is easily possible that less strength existed across the defects than that of typical bulk cemented carbide. Such weakness could contribute to failure by fracture within the carbide during drilling applications. Since cemented carbides and Stratapax blanks can be manufactured without laminations, the uncertainty in strength across such defects is sufficient reason to require the absence of them in the cemented carbide portion of Stratapax blanks.

Several "as-received" Stratapax blanks were fractured perpendicular to the carbide grind surface. A search was made for contamination and lamination line defects similar to that found in H12-1. Contamination was found on two out of the thirteen specimens examined, and these two were probably from the same lot. On both samples, the contamination was intermittent, covered a small percentage of the surface, and was similar to that shown in Figure 7a. It is possible that the observed contamination was grinding debris trapped in deeper than average grinding grooves. This could account for the contaminant elements found on H12-1. No lamination line defects were found.

A low magnification SEM photomicrograph of the steel stud side of the failure fracture surface is shown in Figure 8a. A number of linear light areas parallel with the grinding marks are observed over the surface, with the majority of the surface being light gray in color. A higher magnification photomicrograph in Figure 8b depicts a typical light area. The light areas were tungsten carbide particles with no evidence of ductile cobalt failure.

(a)

(b)

Figure 8. Failure fracture surface on the stud side of H12-1. (a) 25X, (b) 5000X.

In Figure 9, we compare the fracture surface on the Stratapax side with the gray areas of the fracture surface on the steel stud side. They are similar to each other and both are remarkably similar to an "as-received" cemented carbide grind surface. (Compare Figure 9 with Figure 10.) There is very little evidence of ductile shear failure in Figure 9; the features in Figure 9 are characteristic of an unbonded surface. (Compare Figure 9 with Figure 5 where evidence of ductile failure does exist.) SEM elemental analysis using x-ray fluorescence identified only iron in the gray areas of Figure 8a and tungsten with minor amounts of iron and even less cobalt

(a)

(b)

Figure 9. Failure fracture surfaces of H12-1. (a) Stratapax side, (b) stud side. (5000X).

in the light areas. A similar elemental analysis on the Stratapax side of the failure detected tungsten, iron and cobalt at concentration levels similar to the light areas on the stud side. From these results we conclude that the failure occurred at the carbide-steel bond surface and that most of the area had not bonded at all. Areas which were bonded failed in the carbide where little cobalt existed, a circumstance similar to Group A in bond run "L" discussed previously. Contamination at the bond surface was responsible for little or no bond being formed.

Though it apparently was not responsible for the low load failure of H12-1, an additional serious factor is observed in

Figure 9a. The morphology shown is that of the unbonded carbide surface. In the upper left corner we note an area where the surface grind region had separated from the carbide grains immediately beneath the surface. Stratapax blanks with grind damage of the depth recorded here will have decreased strength in the carbide near the bond joint and can be expected to fail at lower loads than Stratapax blanks with minimal grind damage. As noted previously, more extensive grind damage was observed on "H" run carbide surfaces than on other runs; hence, this problem was characteristic within the "H" run. The reader is reminded that only failed element H12-1 was examined from run "H." Other cutter elements from run "H" were not examined because they were no longer available at the time of this investigation. It would not be surprising to learn that some of these cutter elements had failed because of grind damage.

Recommended Solution

In this study, we examined Stratapax-steel stud cutter assemblies which failed at significantly less than typical load stresses. In most cases, the failure mechanism was cemented carbide related, and in each of these cases, the removal of 75-125 microns of carbide material would have eliminated the problem. The cobalt depletion region was 30 microns deep, the surface contamination was less than 15 microns deep, the carbide grind damage layer was at most two or three microns deep, and the laminations were up to 45 microns deep. It is

recommended that more than 75 microns be removed in grinding to ensure, in production, that a flat surface is maintained and that at least 50 microns are removed at all points on the surface. A safety margin may be needed to account for deviations from lot to lot.

Even though cemented carbides are hard, they can be damaged by abusive grinding. Grinding generates debris of fractured tungsten carbide particles, grinding medium particles, bonding resins, etc. of the grinding wheel and cobalt which can be partially smeared over the other debris particles. Tungsten carbide particle pullout results in surface porosity which may be partially filled or bridged, subsequently, with mechanically bonded debris. The grinding debris can fill or partially fill grinding grooves in the same way. Subsurface porosity is generated in this manner. During grinding of cemented carbides, a surface grossly different from the bulk carbide material can be produced; specifically, a few tenths of a micron layer of weakly bonded tungsten carbide particles with excessive porosity relative to the bulk can be generated. This type of surface would be catastrophic for diffusion bonding. A strong bond may be made with the top of this layer but the weak subsurface material would lead to low failure loads. A metallizing layer or steel will deform into the surface irregularities but will not penetrate deeply into the subsurface thereby healing the weakness present there. The coarser the grinding medium, the deeper the depth of cut and the larger the feed, the thicker the damage layer becomes.

To illustrate the criticality of grinding parameters, two grind schedules were completed which were then compared to "as-received" carbide grind surfaces. For the first grind schedule, a 250 grit resinite diamond bonded wheel with a diamond concentration of 100 was used to remove 125 microns of material. A 25 micron depth of cut was used to remove the first 75 microns and a 12.5 micron depth of cut was used to remove the final 50 microns. In the second grind schedule, the same procedure was followed except a 180 grit wheel was used and 200 microns were removed with a 37.5 micron depth of cut before the final 50 microns were removed with a 12.5 micron depth of cut. We show SEM photomicrographs of the ground cemented carbide surfaces in Figure 10 and of fracture surfaces perpendicular to the ground surfaces in Figure 11. These photomicrographs verify that more surface damage was present for the more severe grind schedules. The most damage was observed on the "as-received" Stratapax blanks, and these blanks were typical, not like those with more severe grind damage like run "H." For best results, a 220 grit resinite diamond wheel should be used with several sequential finish grinding passes of 25 and 12.5 microns depth of cut, respectively. Proper attention must be given to cleaning procedures to remove all of the grinding debris.

(a)

(b)

(c)

Figure 10. Ground Stratapax carbide surfaces. (a) "as-received," (b) grind schedule 2, 180 grit diamond wheel, (c) grind schedule 1, 250 grit diamond wheel. (5000X).

(a)

(b)

(c)

Figure 11. Fracture surfaces perpendicular to the ground surfaces depicted in Figure 10. (a) "as-received," (b) grind schedule 2, 180 grit diamond wheel, (c) grind schedule 1, 250 grit diamond wheel. (5000X).

SUMMARY

The low load value required to fracture Stratapax-steel stud cutter elements within Group A was a direct consequence of a cobalt depletion region on the surface of the carbide portion of the "as-received" Stratapax blanks. On one specimen, it was shown that the cobalt depletion region extended 30 microns below the surface. No evidence of a weak gas pressure bond between the carbide and the steel stud was identified. Fracture occurred entirely within the cobalt depletion region of the carbide part of the Stratapax.

Within Groups B and C, the fracture plane was primarily within the steel stud but was near the steel-carbide and the steel-nickel metallization layer, respectively. The carbide portion of the Stratapax was found to have typical properties and was not responsible for the low failure loads. No defect was found at the bond joint. The material weakness of the steel was not identified, but contamination was suspect.

The low failure loads in bond run "H" were due to the presence of contaminants at the bond surface; aluminum and silicon oxides were the major contaminants. It was believed that the contaminants were introduced during grinding. A thin layer of cobalt depleted carbide was identified on the carbide surface of one Stratapax blank which could have caused failure before expected load values were reached. In addition, evidence of a severe grind schedule was identified which may have contributed to the low failure loads. The linear lamination defects probably did not contribute to the low failure loads, but

they should be eliminated for maximum fracture resistance during drilling.

It was recommended that a finish grind schedule be incorporated into the specimen preparation sequence prior to gas pressure diffusion bonding. At least 75, and preferably 125, microns should be removed with a fine, final depth of cut. A resinite diamond grinding wheel with 220 grit diamonds, or finer, should be used.

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