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Field Testing of Abrasion Resistant Carbides

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FIELD TESTING OF ABRASION RESISTANT CARBIDES

by

Kevin C. Orme

Thesis submitted in partial fulfillment
of the requirements for the degree

of

DEPARTMENT HONORS

in

Industrial Technology and Education

Approved:

Thesis/Project Advisor

Department Honors Advisor

Director of Honors Program

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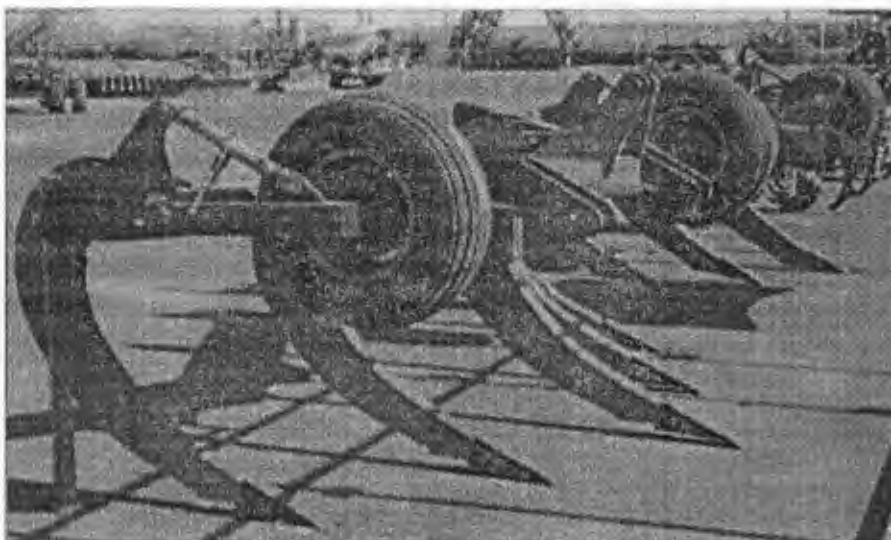
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ABSTRACT

Chromium, tungsten, titanium, and vanadium carbides were investigated to determine relative cost of operation for each in an agricultural environment. For use on a ripper plow, these carbides were field tested in two different soil types; one soil having a matrix of gravel and cobblestones, and the other consisting of hard dirt and large underground rocks. Each alloy was applied to a high carbon plow point using an arc welding process. Along with the welded points, cast chromium carbide was tested. The results are given in price per acre and not solely longevity of the point. It was concluded that wear resistance is highly dependent on the abrasive environment. Each soil had a different effect on the amount of wear obtained for every alloy tested.

INTRODUCTION



RIPPER PLOW

This is a picture of an agricultural implement called a ripper, which is used to shatter ground that has become hard. The shanks are roughly 30 inches long with replaceable points on the ends. This plow is pulled through the ground at a speed of approximately 5 miles per hour and at a depth of 16-24 inches. Due to the severe wear that they are exposed to, the points must be replaced frequently and this can lead to expensive upkeep. Common points today range from \$18-\$100+ and can last anywhere from 200-2000+ acres.

This report covers the abrasion resistance of different carbide compounds applied to the points of a ripper plow. Four carbides were chosen from their reputation in industry as "the best for wear resistance". Chromium, tungsten, titanium, and vanadium carbides were applied to ripper points and field-tested in two different soil compositions and the data recorded gives a relative price per acre for each carbide. The chromium carbide was tested as a wear facing welded directly onto the top of the point, and also as a cast piece separately welded onto a point. The other three carbides were welded on directly as wear facing material.

More often than not, plow points are rated on the length of time that it takes them to wear out and no consideration is given to the cost of the point. This experiment demonstrates the actual costs associated with different materials and not just the length of time that they last. The results will demonstrate that it is not always the material that lasts the longest that is the most cost effective.

PURPOSE

Over the years, rating the effectiveness of ripper points has been strictly done by how many acres the point will go before it is worn out. The trouble with this method is that it does not take into consideration of the cost of the point and the fuel needed to pull that point through the soil. Cast points are very popular due to the amount of acres they can do before wearing out. In order for a cast part to be welded onto a point, it has to be cast larger than the base onto which it will be welded. At depths up to 24 inches in hard soil this extra surface area creates an enormous amount of drag and fuel consumption. As a result time is lost from going a gear slower and more fuel is purchased due to the increased expenditure of energy. The reason for this study is to demonstrate that other materials can be substituted for cast points and be more cost effective.

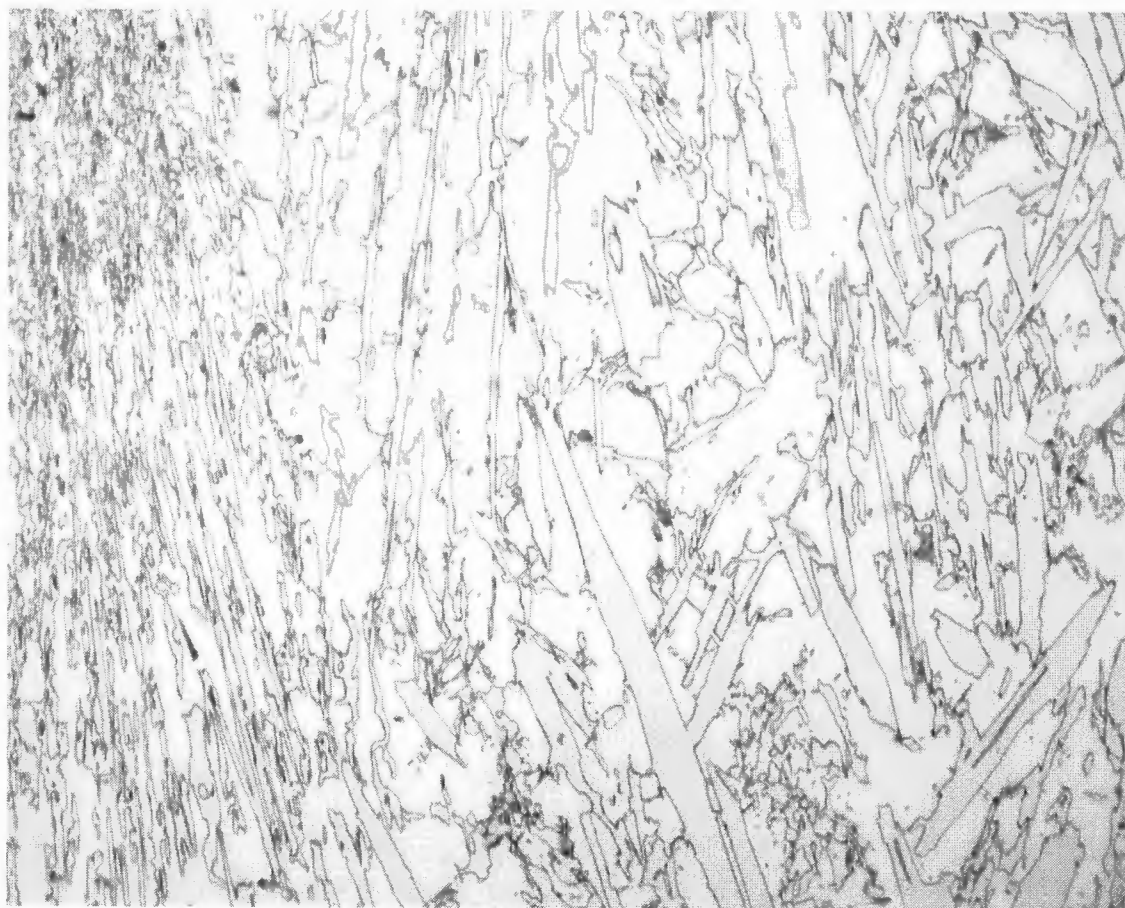
Carbides are considered the most abrasion resistant materials known. Chromium, tungsten, titanium, and vanadium carbides are among the most common carbides applied as wear facing through a welding process. In order to determine which one of these is the most cost effective for agriculture use on ripper plows this study was conducted which involved field-testing of these four alloys. Cast chromium points will also be included in order to determine their effectiveness as ripper points.

This report should demonstrate to the reader that modern wear facing alloys are an economical solution to abrasion resistance caused by metal to earth wear in an agricultural environment.

DEVELOPMENT

Each carbide material was applied to a high carbon steel base, which served as the backbone of the point. The high carbon steel has a high yield point, which gives rigidity to withstand immovable underground rocks that impact the tip of the point and induce large bending stresses that may bend or break the point. The higher carbon content also aids in the carbide formation as the wear facing material is added.

Cast chromium carbide is produced using sand casting methods. A full plate that covers the top surface of the point is cast, and then it is welded onto a high carbon base material that gives rigidity to the point to prevent breakage (See Appendix A). A typical composition for this material is: 23% chromium, 2.7% carbon, 0.75% manganese, 0.6% molybdenum, and 1% silicon. A Rockwell hardness of C51 was measured for this alloy.

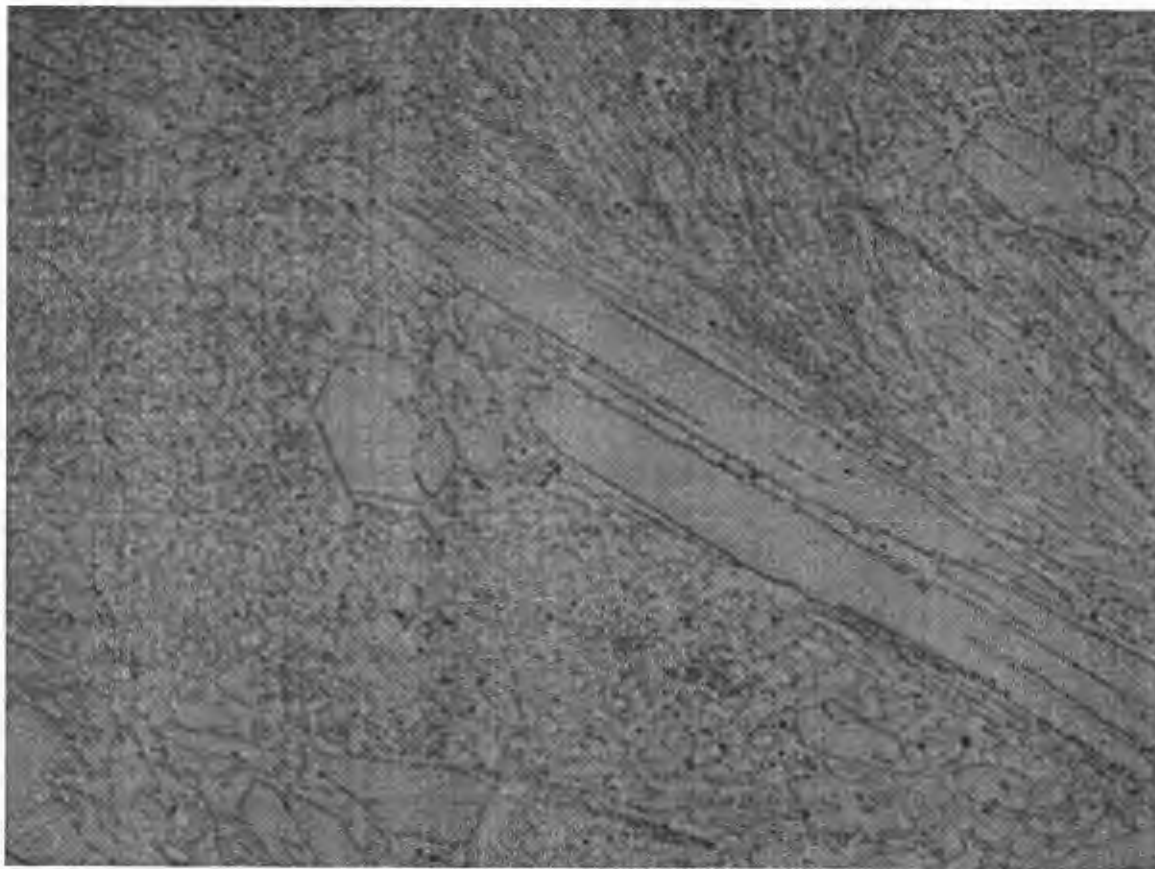


CAST CHROMIUM CARBIDE

The SMAW chromium carbide wear facing electrode had a deposition content typical of 23% chromium, 5% carbon, 0.8% manganese, 2.3% molybdenum, and 0.6% vanadium.

Chromium carbide will polish to a mirror-like finish in abrasive conditions, which gives a low coefficient of friction. This is beneficiary because it allows the dirt to flow over the point with a minimum amount of drag. This low surface friction gives longer life to the point and the tractor uses less fuel and increased speed. The melting point for chromium carbide (Cr_3C_2) is 3434°F and the crystal structure is orthorhombic.

Chromium carbide was applied using a $5/32''$ SMAW electrode. Amperage was set at 160 DCEP and an interpass of no less than 1200°F was maintained throughout the process. This alloy will crack transversely across the weld bead unless temperatures are high enough to allow stresses to disperse. Weld bead-cracking acts as stress points in which propagation of the crack through the base metal can occur, thus causing catastrophic failure and loss of an expensive point. In order to reduce stress cracks in the weld metal a high interpass temperature was maintained, which allowed the base metal to give to the build up of weld metal on the surface. A Rockwell hardness of the wear facing was measured at C58.

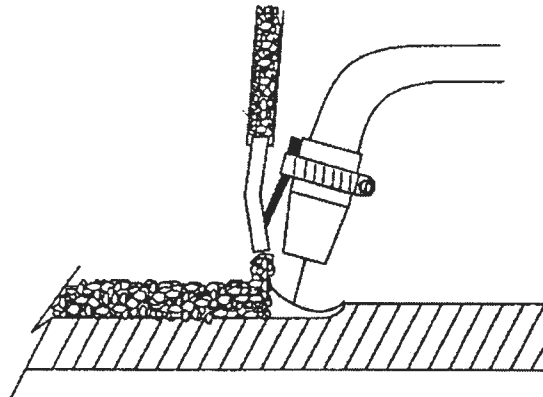


WELDED CHROMIUM CARBIDE

In both the cast and the welded chromium carbide microstructures, the carbides are seen as long needles that are large in size. Surrounding the larger carbides are smaller sized ones that cross in all planes. These larger carbides are less likely to pull out of the matrix from friction on the surface. This could be the reason chromium carbide performs so well as a wear resistant material.

Tungsten carbide is considered to be the hardest in the carbide family; however, the melting point for tungsten carbide is not the highest out of the carbides. In general, the melting point of a compound can be an indication of its bond strength and hardness.

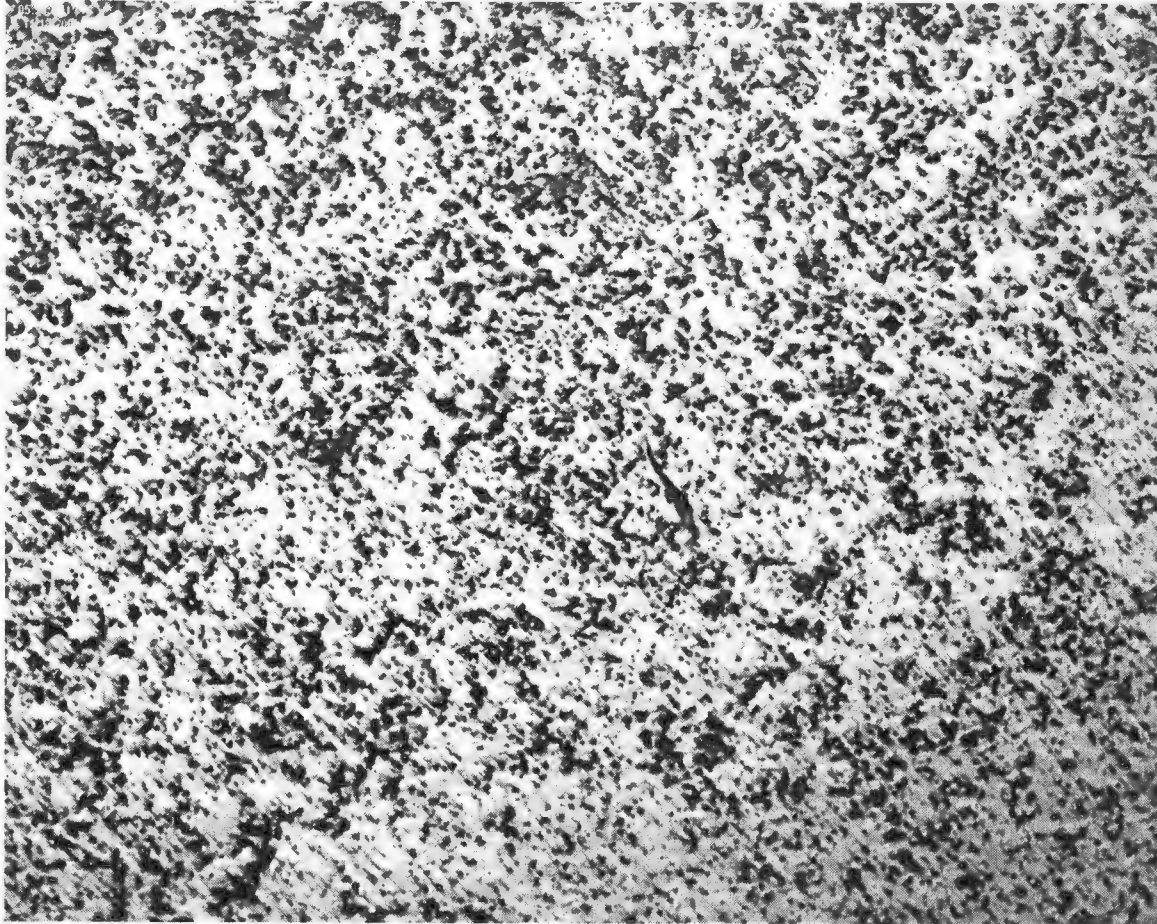
One of the disadvantages of applying tungsten carbide with any arc welding process is the dissolution of the carbides while traveling across the arc. Once dissolved, the reformation of large carbides in the weld puddle is retarded. A new method of applying the carbide into the



matrix was developed in order to retain large tungsten carbides in the matrix. This involves using a GMAW process in which a molten matrix is created and the high melting point tungsten carbide is dropped into the weld puddle after the arc. This allows the carbides to saturate the matrix material without being melted by the arc. Depending on the carbide mesh size, this method can produce an extremely rough surface like rough sand paper. This rough surface allows dirt to be trapped throughout the part and protects the matrix material from being abraded away while the large carbide pieces take the wear. Tungsten carbide can be found in two carbide forms: WC melts at 5198° F and has a hexagonal crystalline structure, and W₂C which melts at 5050° F and also has a hexagonal crystalline structure.

The equipment needed to apply tungsten carbide in this form was not available. A company was contacted that offered to apply 20x30 mesh size tungsten onto the points. Due to the rough surface of tungsten carbide, actual Rockwell hardness measurements could not be performed.

The titanium carbide used had a nominal alloy content of 19%, which includes carbon, manganese, chromium, molybdenum, and titanium. This alloy is advertised as having very good abrasion resistance and good impact resistance. It can be applied in multiple layers without risk of spalling and minimal cross-checking. This is important for ripper plow applications where large rocks cause severe impact stresses. The melting point for titanium carbide (TiC) is 5684° F, higher than tungsten carbide, and the crystal structure is cubic.



TITANIUM CARBIDE

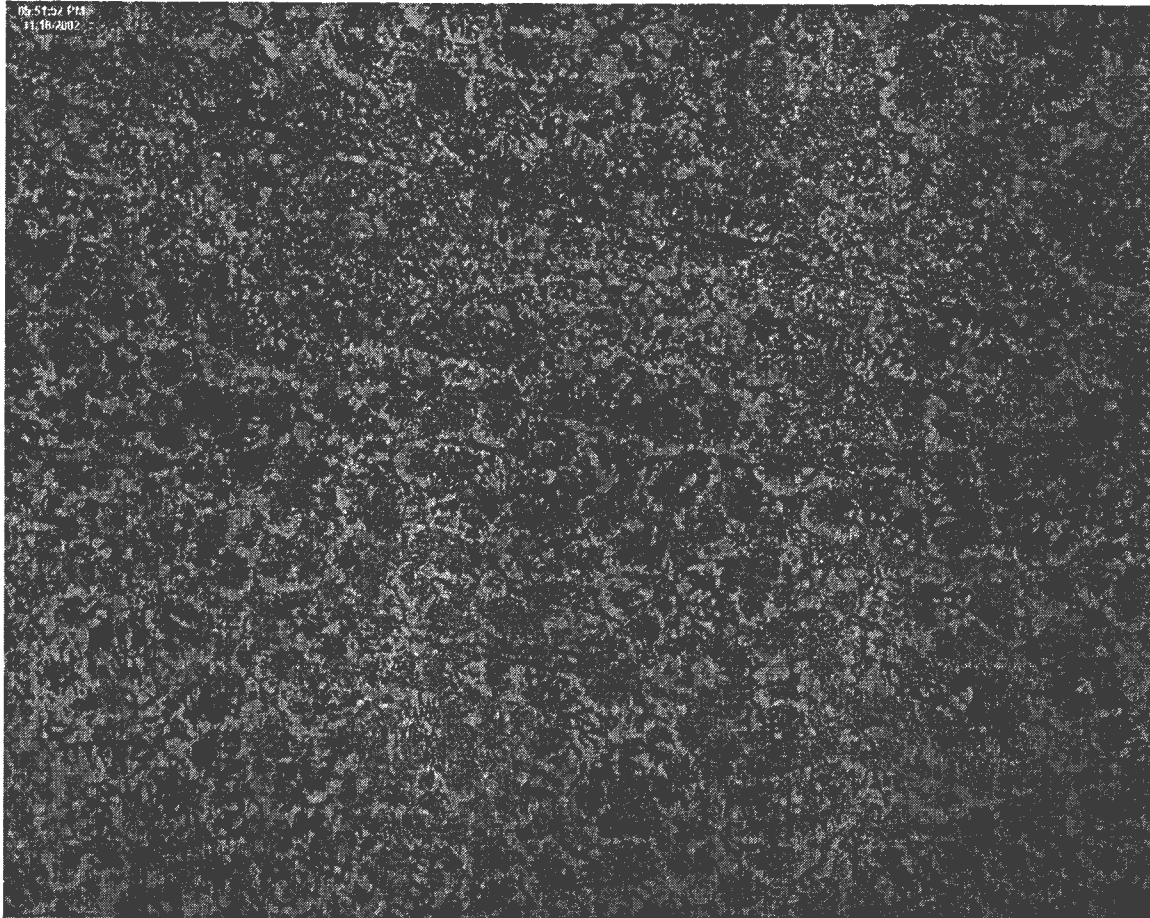
The titanium carbide alloy used was an open arc FCAW type wire. It produces only a small amount of slag that is easily removed. Using DCEP with a 1/16-inch wire, the volts were 24, amperage 160, and wire speed at 300 inches per minute. Interpass temperature was maintained at 500° F to prevent cracking of the base metal. Hardness was measured at Rockwell C 46.

The small black dots in this microstructure are the titanium carbides. Compared to the chromium carbides, they are very small. This can be to a disadvantage because they can be pulled out of the matrix easily when encountered with a gouging affect from abrasion. If the abrasive material is small in grit then this tendency to be pulled out is less. This theory explains why the titanium carbide performs better in the hard dirt, which has a tendency to polish metal, as opposed to the gravelly soil, which tends to gouge the metal more than polish.

Vanadium carbide is extremely expensive to produce. This puts a high price tag on anything that has much vanadium in it. The overall alloy content of the vanadium carbide used for this project was 29% (vanadium, tungsten, carbon, manganese, molybdenum, and nickel). The unique characteristic of this carbide is its ability to dissolve in the arc and then rapidly reform before solidification of the weld metal. Vanadium carbides help

to produce a fine grain structure in the matrix. Fine grains are desirable to most metals because it is much stronger and ductile than a large grain structure. One major disadvantage to this alloy is the dull surface created during service. This type of surface creates a large amount of friction, which in turn creates heat and pulls the carbides out of the matrix rather than wearing them down. Vanadium carbide has two carbide forms that are quite different. One is VC, which melts around 5090° F, and the crystal structure is cubic. The other is V₂C, which melts at 3930° F and has a hexagonal crystal structure.

It was not determined which of the two carbides exist in this microstructure. Perhaps, due to the lower melting point of V₂C, the bond is weaker and thus the wear resistance is lowered. If this statement is true and this alloy is comprised mainly of V₂C then that would explain why this alloy did not wear as good as the others.



VANADIUM CARBIDE

The vanadium carbide was applied with a FCAW process using a CO₂ shielding gas. The current was DCEP at 180 amperes. Voltage was set at 22.5 with 186 inches per minute and a 1/16-inch wire. The interpass temperature was set at 500° F. Hardness was measured at Rockwell C 40.

Before any material was applied to the points, each individual point was weighed. Once the wear facing was applied and allowed to cool, they were weighed again. This gave an amount of weld metal that was applied to each point. The slag produced by each of the different alloys was minimal and did not significantly affect the weld metal measurement. These numbers were then applied to the final data in order to determine the price difference of each point with the different alloys applied. The lengths in inches were then recorded for each point. This data was then used to determine the amount of wear incurred on each point after field-testing.

Two different soil types were chosen for this test. Soil 1 had a large amount of gravel and cobblestones in moist dirt. This soil is notorious for its extreme abrasion on ripper points. Soil 2 was mainly hard, packed dirt and sand with large granite rock buried underneath the surface. The finer consistency of this soil polishes the points to a smooth, mirror like finish.

RESULTS

Soil 1							
Carbide Type							
Acres	Cast Cr	Chrome	Chrome	Cast Cr	Titanium	Tungsten	Vanadium
0	12-1/4"	11-7/8"	11-13/16"	12-1/4"	11-15/16"	12"	11-7/8"
110	12-3/16"	11-9/16"	11-5/16"	12-1/16"	11-11/16"		11-7/16"
155	12-3/16"	11-3/8"	11-1/16"	12"	11-1/2"		11-3/16"
200	12-3/32"	11-3/16"	10-15/16"	11-7/8"	11-11/32"		10-13/16"
250						11"	
300	11-31/32"	10-7/8"	10-3/4"	11-25/32"	10-7/8"		10-1/32"
Δ Length @ 250						1.0000	
Δ Length @ 300	0.2813	1.0000	1.0625	0.4688	1.0625		1.8438
Total Acres per Point	3467	900	847	2080	847	750	488
Acres per Inch	1067	300	282	640	282	250	163
Price per Acre	\$0.013	\$0.020	\$0.020	\$0.021	\$0.025	\$0.040	\$0.080

Soil 1 is a mixture of gravel and cobblestones in a wet dirt matrix. Results obtained indicate that chromium carbide is the cheapest choice for this soil type. The cost is only around 1.3-2.1 cents per acre plowed as compared to 8 cents per acre. What these results do not show is the cost of fuel and labor. Drag on the tractor will greatly influence speed of pulling and the amount of fuel consumed. Pulling a ripper through the ground can be likened unto a knife cutting through leather. If the knife is sharp and thin, then the amount of force needed to cut through the leather is minimal compared to a knife that is dull and thick. Cast points are bulky and blunt. This means that a lot more force is needed to pull them through the ground when compared to a sharp, skinny point. So, if fuel and labor were to be factored into the equation, the result would be that the cast chromium points would be much more expensive to run than the welded chromium carbide points.

The titanium and the tungsten were comparable to the chromium carbide in the amount of acres per point achievable, but due to the high cost of the alloy itself they do not add up to be economical in this soil. Vanadium carbide simply did not perform as satisfactory as anticipated, probably due to its higher coefficient of friction.

Soil 2

Carbide Type

Acres	Tungsten	Titanium	Chrome	Chrome	Vanadium	Cast Cr
0	12"	11-7/8"	11-11/16"	11-7/8"	10-5/16"	12-1/4"
120	12"	11-11/16"	11-5/8"	11-5/8"	9-7/16"	
160						11-5/8"
510					8-3/16"	
555	12"	10-9/16"	9-7/16"	9-5/8"		
Δ Length @ 160						0.625
Δ Length @ 510					2.125	
Δ Length @ 555	0	1.3125	2.25	2.25		
Total Acres per Point	**	1269	740	740	720	832
Acres per Inch	**	423	247	247	240	256
Price per Acre	**	\$0.016	\$0.022	\$0.022	\$0.043	\$0.060

Soil 2 consists of extremely hard, packed soil with large underground rocks and practically no moisture content. Tungsten carbide has proven itself to be the number one cost effective point for this class of soil. Currently this point has covered over 1200 acres with no loss in length. The drag is slightly greater for this type of tungsten carbide application than the welded chromium, titanium, and vanadium carbide points; however, the longevity of the point outweighs this small amount of drag. In second place is the titanium carbide at 1.6 cents per acre and closely following is the welded chromium carbide. Once again the vanadium carbide proved to be a poor performer of abrasion resistance in this soil. The cast chromium carbide wore poorly and had to be taken off after 160 acres because it pulled so hard that it would not stay in the ground.

In both soil types large pieces of the cast chromium would break off due to impact and fatigue. When this happens money is wasted from the lost piece and the tip of the point is blunted. With a broken off tip, it takes many acres for it to sharpen up again. The wear-facing points were able to handle impact better than the cast points. When extreme impact was encountered, the wear facing would chip off in small pieces. These damaged areas quickly sharpened to create a new edge to cut through the dirt. This happened because the wear-facing layer was much thinner in cross-section than the cast points.

CONCLUSIONS

Laboratory tests of abrasion resistant alloys yield definite results on individual alloys that are then advertised as constant for any environment. Each alloy is given a relative abrasion and impact resistance rating on a chart that is then used to determine the best alloy for a particular situation. This field investigation of abrasion resistance of carbide compounds shows that every environment is different on wear. There is no one alloy that will out perform the rest in all situations. In order to find the most economical wear-facing alloy, an individual field study must be performed on each specific environment. As in this experiment, differences in soil composition were able to yield diverse results, and the different soils were only 30 miles apart.

“Abrasion resistance is proportional to hardness” is a common rule of thumb stated today. The results from this experiment show that hardness is not necessarily an exact measurement of wear resistance. If that were the case, each soil type would have yielded the same results. By looking at the acres per inch of each point it is obvious that the hardest material did not always demonstrate the best abrasion resistance.

With tradition leaning toward cast chromium carbide points for ripper plows, this study is important because it demonstrates the cost effectiveness of using wear facing electrodes. The points that had wear facing applied were not always the ones that lasted the longest but they were the best economically. Fuel consumption is lower, the tractor can pull them faster, and they are cheaper to apply than expensive, hard pulling cast points.

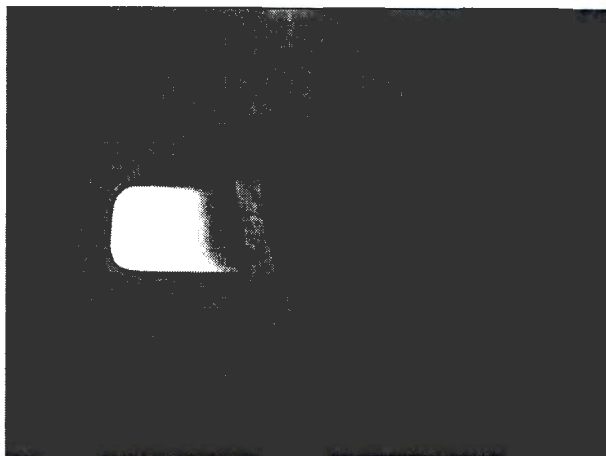
Based on the test results, it is recommended to use chromium carbide or titanium carbide on soils similar to Soil 1. This means soils that have a high gravel and cobblestone content with a moist matrix of dirt. For soils of similar composition to Soil 2, hard, packed dirt with large underground rocks, tungsten carbide applied using the process described in the development section with a mesh size of 20x30 or titanium carbide is recommended. In either of the two types of soil, the vanadium carbide is not recommended.

Further research on this subject could cover the amount of drag and fuel consumption that is related to each of the different point configurations. That, along with the results from this experiment, would give more precise data for choosing the most cost efficient point to use on a ripper plow with soil compositions similar to Soil 1 and Soil 2.

SUMMARY

A study was conducted which compared the relative abrasion resistance and economics of four carbide compounds (chromium, tungsten, titanium, and vanadium carbides) when applied to ripper plow points in an agricultural environment. Each of the four carbides was applied using an arc welding process; the chromium carbide was also tested in the cast condition. Two different soil compositions were chosen for field-testing of these alloys. One soil had a matrix of gravel, cobblestones, and moist dirt. The other soil was extremely dry, hard dirt with immovable underground rocks. The results varied for the different soil types that lead to the conclusion that not all wear facing materials react the same for different abrasive environments. Also, the hardest materials are not always the best for abrasion resistance and it is not always worth paying more for these alloys.

APPENDIX A- CAST AND WELDED CHROMIUM CARBIDE POINTS



CAST CHROMIUM CARBIDE



WELDED CHROMIUM CARBIDE



TITANIUM CARBIDE

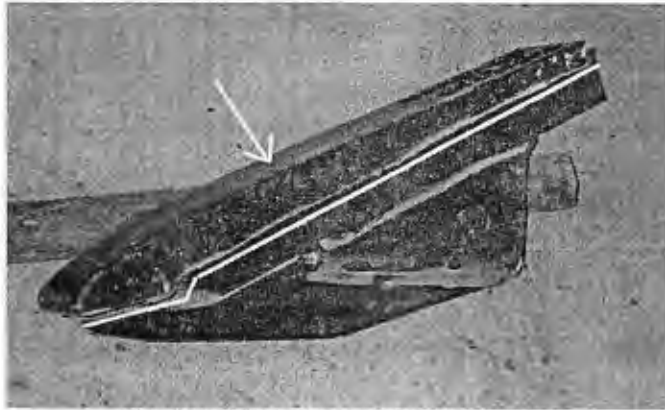


VANADIUM CARBIDE

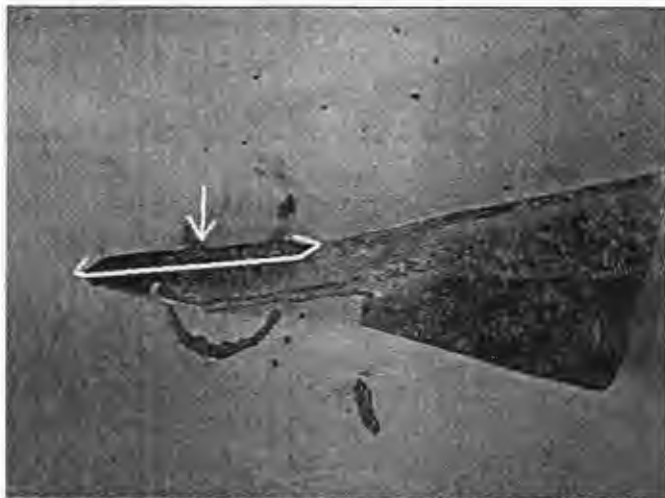


TUNGSTEN CARBIDE

APPENDIX B- POINTS AFTER 300 ACRES SERVICE (SOIL 1)



CAST CHROMIUM CARBIDE



WELDED CHROMIUM CARBIDE (SIDE)



WELDED CHROMIUM CARBIDE (TOP)