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INTERIM REPORT ON THE EVALUATION OF PLOUGHSHARE MATERIALS

by

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PHYSICAL METALLURGY DIVISION

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SUMMARY OF RESULTS

The first two parts of a project designed to evaluate new materials for use as ploughshare points have been completed and the results obtained are listed in this report. The first part gives data obtained as to the composition, microstructure and hardness of ploughshare points commonly used today. From these results, eight materials were chosen for testing in Part Two of the project. These represented compositions with varying degrees of abrasive wear resistance and impact resistance. These materials were tested as cultivator teeth under closely controlled field tests and the results analyzed statistically. From these results, four materials have been selected to be tested as ploughshare points in the third part of the program. Laboratory impact tests on these four materials are also to be carried out.

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INTRODUCTION

In a letter dated July 15, 1958, the Canadian Federation of Agriculture inquired of the Director of the Mines Branch, Department of Mines and Technical Surveys, as to the possibility of this Branch carrying out tests designed to evaluate different ploughshare materials. It was stated that, with the wider use of modern tractor-drawn ploughs, the operator was less sensitive to obstacles such as stones in the soil and plowing speeds are greater. The result was a reduced service life in the ploughshare points. It was requested that testing be carried out in an attempt to obtain a better material for use with tractor-drawn ploughs.

This report is divided into three parts. The first deals with the analysis, hardness and microstructure of ploughshare point materials commonly used. Part Two reports the results of wear tests carried out on several materials used on cultivators, and Part Three lists the proposed additional tests to complete the project.

PART ONE

Experimental Procedure

The Canadian Department of Agriculture supplied ploughshare points from five different manufacturers, referred to in this report as A, B, C, D and E. Five different designs were involved and three different materials, viz cast iron, steel and nodular iron, were used. Samples or drillings were removed from each different material from each manufacturer for chemical analysis, hardness and metallographic examination. The hardness and metallographic specimens were taken from the toe, blade and sole positions of the ploughshare points. Photographs in Figure 1 show the five different designs and the locations from which hardness and metallographic specimens were taken.

Chemical Analyses

Examination of some of the ploughshare points indicated that the blade and sole portions were welded together. Consequently, drillings for chemical analyses were taken from both the blade and the sole. The chemical analyses are given in Table 1.

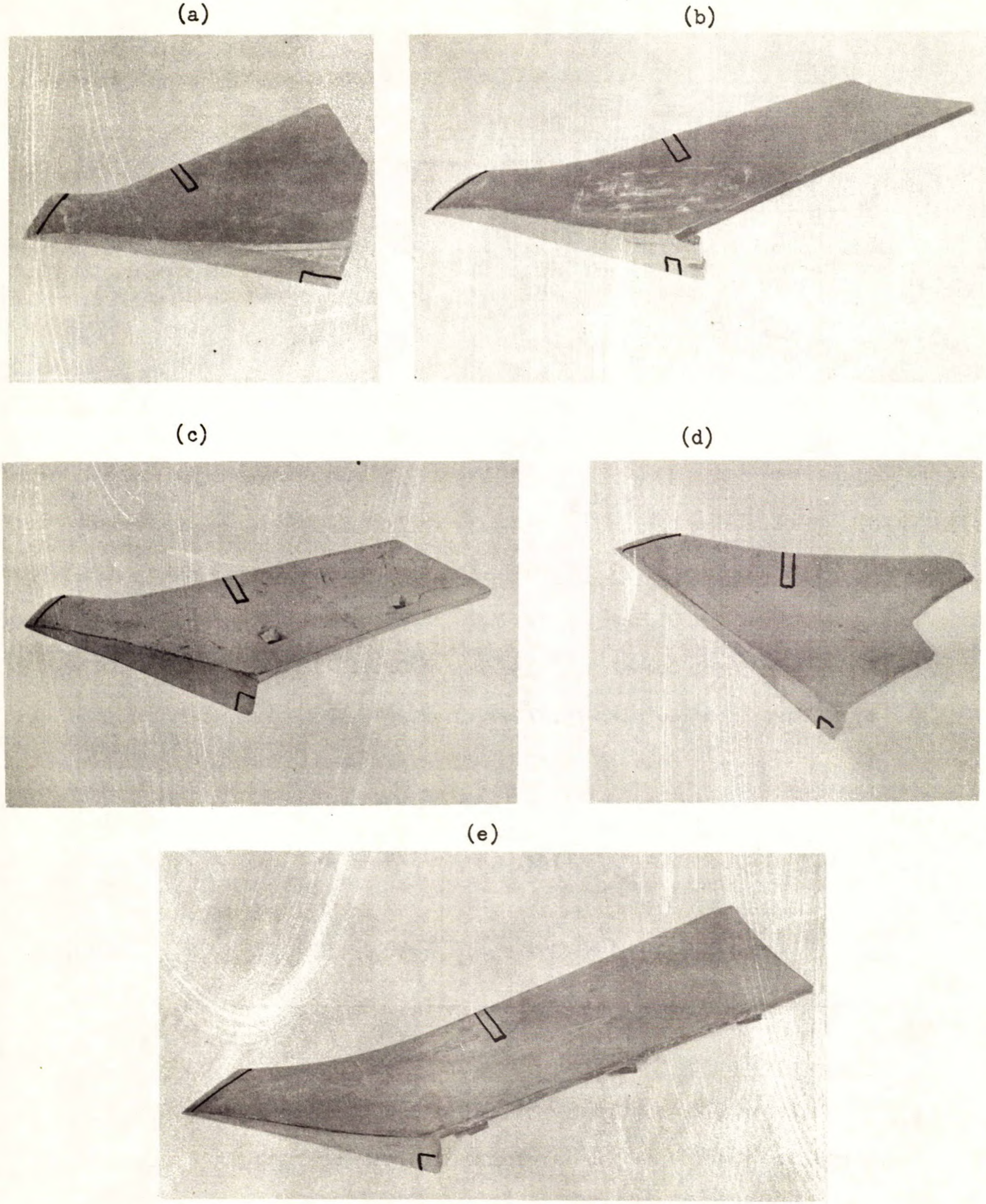


Figure 1. - Photographs of the five different designs of ploughshare points supplied. The locations of the hardness and metallographic specimens are drawn on the points.

TABLE 1

Chemical Analyses of Ploughshare Points from Five Manufacturers

Manuf. Code No.	Type of Material	Location of Analysis	Element (%)						
			C	Mn	Si	S	P	Cr	Ni
A	Steel	Blade	.90	.83	.20	.047	.022	.04	<.01
	"	Sole	.10	.37	.05	.032	.017	.03	<.01
B	"	Blade	.85	.72	.23	.026	.020	.12	.09
	"	Sole	.23	.40	.09	.014	.017	.05	n.d.
C	"	Blade	.86	.70	.16	.033	.021	.06	.03
	"	Sole	.10	.34	.03	.035	.014	.08	.01
D	"	Blade	.80	.33	.18	.027	.008	n.d.	.02
	"	Sole	.10	.40	.02	.050	.012	n.d.	.01
E	"	Blade	.87	.78	.21	.043	.020	n.d.	.01
	"	Sole	.20	.48	.08	.020	.008	n.d.	.01
A	Cast Iron	Sole	3.47	1.10	2.24	.10	.33	.83	.04
B	"	Sole	3.47	.79	2.67	.085	.15	.08	.02
C	"	Sole	3.56	.61	2.44	.10	.42	.73	.05
D	"	Sole	3.39	.80	1.74	.127	.49	.13	.07
E	"	Sole	3.22	.89	2.79	.088	.15	.06	n.d.
E	Nodular Iron	Sole	3.51	.37	2.28	.018	.15	.16	.09

Hardness Tests

The samples for hardness examination were removed from the ploughshare points at the locations indicated in the photographs in Figure 1. Rockwell hardness readings were used throughout. It is realized that the Brinell hardness test is usually preferred for cast iron and nodular iron but was not used here since the sections involved were all too small. The Rockwell readings do, however, give an indication whether or not the area examined had been heat treated or chilled to produce a higher hardness. The hardness results are listed in Table 2. Surface readings are hardnesses taken as close to the surface as possible. Centre refers to the centre of the section involved. Readings are Rockwell "C" unless otherwise indicated.

TABLE 2

Rockwell Hardness Results for the Ploughshare Points Supplied

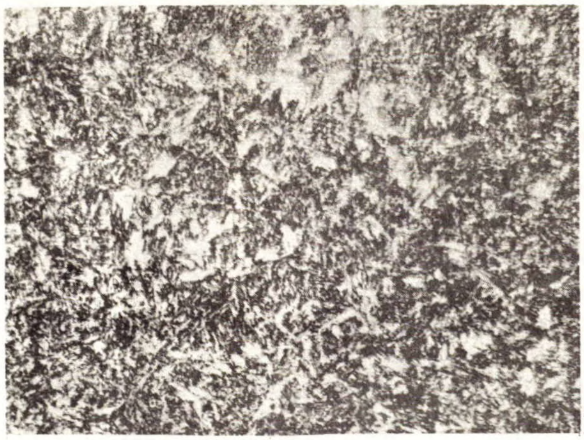
Manuf. Code No.	Material	Rockwell Hardness for Various Locations					
		Toe		Blade		Sole	
		Surface	Centre	Surface	Centre	Surface	Centre
A	Steel	61.5	34	32	29	55 R'B'	64 R'B'
B	"	25	25	20	18	60 R'B'	65 R'B'
C	"	97 R'B'	85 R'B'	95 R'B'	95 R'B'	42 R'B'	43 R'B'
D	"	47	44	28	24	45 R'B'	55 R'B'
E	"	23	23	24	23	67 R'B'	67 R'B'
A	Cast Iron	51	48	50	20	24	21
B	"	97 R'B'	97 R'B'	40	90 R'B'	87 R'B'	87 R'B'
C	"	36	35	40	20	18	16
D	"	48	49	51	20	19	14
E	"	24	22	30	15	86 R'B'	90 R'B'
E	Nodular Iron	28	28	30	15	91 R'B'	91 R'B'

Metallographic Examination

The samples used for the hardness tests were used for metallographic examination. For the steel ploughshare points, the ones from companies A and D had received a quench and tempering treatment, and the steel point from company C appeared to have been annealed. B and E companies did not perform any heat treatment on the points, both steels exhibiting a microstructure typical of the as-rolled condition for this type of steel.

The cast iron points made by companies A and D had been cast against chills in a manner to produce a white iron structure on the tip and along the leading edge of the blade. It is believed that this was also done on the points manufactured by companies C and E. However, these companies had also carried out some stress relief or low temperature anneal on the points as well. It is believed the nodular cast iron point was treated in a similar manner. The cast iron point from company B may possibly have also received such a treatment, but this is more difficult to tell. Microstructures in the tip samples of a steel, a cast iron and a nodular iron point are shown in Figure 2.

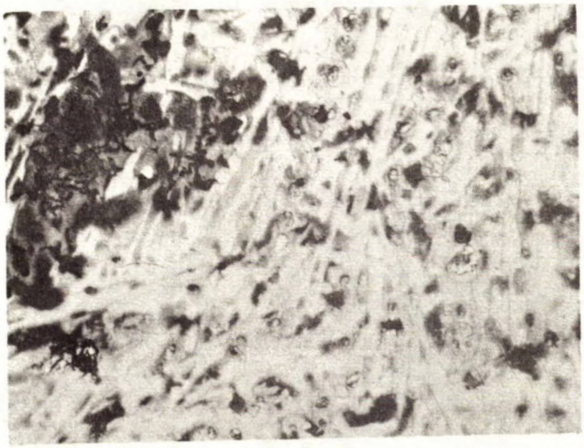
(a)



Steel ploughshare.

Mag. X500 Etched in 2% Nital

(b)



Chill cast iron ploughshare.

Mag. X500 Etched in 2% Nital

(c)

Chilled nodular iron ploughshare.

Mag. X500 Etched in 2% Nital

<u>Figure 2</u>. - Microstructures of ploughshare points near the tip.

Discussion of Part One

The steel ploughshare points examined were all fabricated, rather than cast, and were made of two different grades of carbon steels. The blades were of AISI 1080 steel, while the soles were of a lower carbon steel, AISI 1010 or 1020 steel. Two companies had given the points a quench and tempering treatment, which should increase the wear resistance to some extent.

The majority of the cast iron points had been cast against a chill to increase the hardness on the tip and along the leading edge of the blade. Some companies had endeavoured to reduce the hardness of the chilled areas by heat treatment, which probably would reduce the tendency to failure under impact loads.

The nodular iron point appeared to have been cast in a similar manner (against a chill) and had been heat treated to increase the ductility of the chilled portion.

Of the three general classes, the nodular iron and the quenched and tempered steel points would be expected to produce the best wearing qualities and to show some resistance to failure under impact or suddenly applied loads.

PART TWO

Introduction

The examination of the various ploughshare points carried out in Part One gave some indication as to the type of material likely to be best suited to this application. However, because the commonly used ploughshare points are said to be breaking more often when used with tractor power, materials with higher impact strength are indicated. Consequently, a number of materials were selected which were felt to possess quite a wide range of both wear resistant and impact resistant properties.

One problem which presented itself was the difficulty in evaluating all these materials under fairly closely controlled conditions. Testing ploughshare points would mean the use of two or three plows and tractors, with the inherent difficulty of controlling the different tractor speeds, type of soils, operators, etc.

It was, therefore, decided to evaluate the materials as cultivator teeth, in a manner similar to that used and reported in the December 1956 Agriculture Engineering ("Wear Tests of Plowshare Materials", by Nuri Mohsenin, H.L. Womochel, D.J. Harvey and W.M. Carleton). In this project, wear tests were carried out on low and high carbon cast irons and nodular iron.

The advantage of using a cultivator tooth for evaluation of wearing properties of a number of different materials is that they can all be mounted on one cultivator for simultaneous testing. Thus, tractor speed and soil condition variables are eliminated. Also, a statistically designed experiment is easily carried out with this type of test. This would permit the evaluation of other factors such as test piece position.

Experimental Procedure

Eight materials were chosen for the evaluation tests. These materials, along with a code number, heat treatment, and hardness are listed below.

Code No.		Heat Treatment	Hardness
A	AISI 1080	Normalized	R'C'31
B	AISI 1080	Quenched & Tempered	R'C'46
C	AISI 5150	" "	R'C'55
D	AISI 1020-hard	Normalized (Base)	R'B'90
	Surfaced with Tube Borium	(Hard Surface)	R'C'65
E	AISI 1020-hard	Normalized (Base)	R'B'85
	Surfaced with Tube Stoodite	(Hard Surface)	R'C'50
J	Chilled Nodular Iron	Stress Relieved	R'C'51
K	High Alloy Cast Iron	" "	R'C'46
H	1.15%C steel	Spherodized, Quenched and Tempered	R'C'58

A pattern was made for a cultivator tooth to fit an eleven tooth cultivator used at the Central Experimental Farm, Department of Agriculture, Ottawa, which had agreed to carry out the testing program. The test teeth were made in the experimental foundry of the Physical Metallurgy Division, and heat treatments were carried out in this Division as well. The hard surfacing was done by the personnel of the Welding Section, Physical Metallurgy Division.

The complete analyses of the teeth used are listed below in Table 3.

TABLE 3

Chemical Analyses of Teeth Used in Wear Testing Program

Material Code No.	Composition (%)						
	C	Mn	Si	S	P	Cr **	Mo
* 1A	.79	.89	.52	.023	.020	.10	-
* 2A	.82	.95	.61	.024	.028	.10	-
B	.81	1.03	.29	.024	.014	.12	-
C	.53	.88	.27	.026	.014	.89	-
D	.24	.54	.15	.033	.018	.06	-
E	.25	.62	.14	.030	.020	.17	-
H	1.15	.91	.42	.027	.023	.26	-
J	3.22	1.36	3.13	.012	.16	.03	-
K	2.66	.88	1.13	.032	.038	17.47	2.80

* Two heats were made of composition "A" and are referred to as "1A" and "2A".

** The chromium contents reported are residual amounts except for compositions "C" and "K".

The statistical design chosen for the tests is known as a Latin Square, in this case an 8 x 8 Latin Square. Eight materials were to be tested, in eight positions on the cultivator (three tooth positions on the cultivator were left vacant, one on each side and one in the centre, leaving 4 tooth positions equally spaced on each side of the central tooth position), and the tests were carried out eight times (eight periods). The time of each test was held to about 14 hours, the tractor speed held to 4 mph as closely as possible, and the same area of land was used on all tests. The 8 x 8 Latin Square as shown in Table 4.

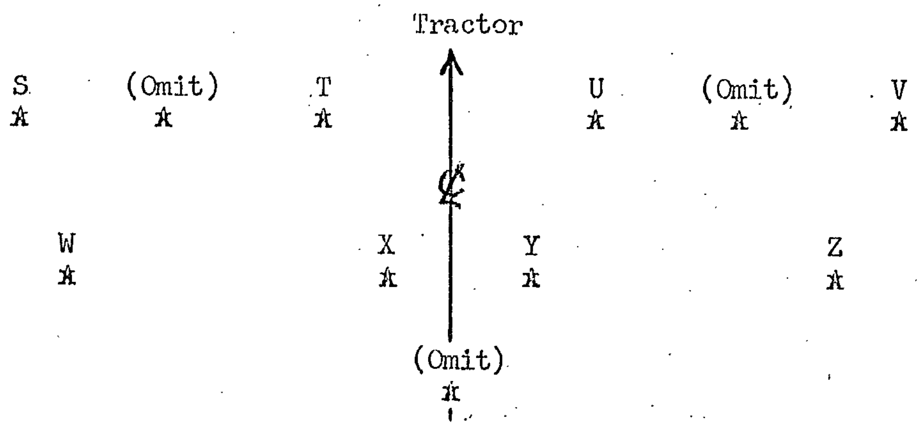
TABLE 4

8 x 8 Latin Square Design of Tests

Test Period	Tooth Material for Tooth Position							
	S	T	U	V	W	X	Y	Z
1	B2	J3	D9	K14	E4	H5	C10	1A8
2	1A6	B7	K6	E14	H3	D7	J13	C4
3	E1	K8	J8	B9	2A8	C9	D10	H12
4	K9	D12	C5	J6	B6	1A9	H6	E8
5	C11	1A1	E12	H16	D13	K12	B14	J1
6	D5	H7	1A3	C2	J19	B13	E5	K10
7	J18	C7	H14	D4	K1	E10	1A12	B11
8	H11	E9	B12	2A11	C8	J20	K3	D3

Note: The numbers after the code letters A, B, etc. refer to the order in which the individual castings were made, ie K14 refers to the composition K, and the 14th casting poured from the heat.

The S to Z tooth positions are shown hereunder.



A table of random numbers was used to select the various teeth to be used in each period, thereby eliminating any possible variation in composition which may have occurred during the pouring of each set of castings.

The teeth were all weighed before and after testing on a scale which was capable of weighing to $\pm\frac{1}{4}$ gram. The loss in weight per hour of testing was used as the criterion for wear resistance.

No special precautions were used in hard facing the teeth with the tube Borium or tube Stoodite. An average of about $\frac{3}{4}$ ounce of the hard facing material was used on each tooth. Only the leading edges of the tooth were so treated.

Results

The results of the wear tests carried out on the cultivator teeth are listed in Table 5. These results are arranged in order for statistical analysis. There are two missing values, one in the first period for composition E, where a piece of the hard facing material chipped off, and one in the fourth period, where a tooth of J composition broke and was lost.

TABLE 5

Wear Data for Cultivator Teeth
(Weight loss in grams per hour)
(Letters in brackets indicate tooth position)

Test Period	Compositions							
	K	C	H	J	E	D	B	A
1	0.178 (V)	0.196 (Y)	0.321 (X)	0.535 (T)	0.293* (W)	0.500 (U)	0.750 (S)	0.947 (Z)
2	0.125 (U)	0.321 (Z)	0.107 (W)	0.214 (Y)	0.785 (V)	0.268 (X)	0.643 (T)	0.625 (S)
3	0.071 (T)	0.036 (X)	0.286 (Z)	0.196 (U)	0.250 (S)	0.071 (Y)	0.517 (V)	0.036 (W)
4	0.124 (S)	0.216 (U)	0.124 (Y)	0.422* (V)	0.310 (Z)	0.526 (T)	0.139 (W)	0.356 (X)
5	0.134 (X)	0.418 (S)	0.485 (V)	0.368 (Z)	0.520 (U)	0.552 ((W)	0.502 (Y)	0.989 (T)
6	0.304 (Z)	0.785 (V)	0.820 (T)	0.518 (W)	1.035 (Y)	0.982 (S)	1.105 (X)	1.285 (U)
7	0.125 (W)	0.715 (T)	0.590 (U)	0.554 (S)	0.715 (X)	1.285 (V)	1.301 (Z)	0.981 (Y)
8	0.143 (Y)	0.161 (W)	0.411 (S)	0.464 (X)	1.071 (T)	1.411 (Z)	0.696 (U)	1.750 (V)

* Statistically-estimated values to replace missing experimental values.

Table 6, below, summarizes the analysis of variance. The F test indicates that there were significant differences between each of the variables, - compositions, test periods, and tooth positions.

TABLE 6

Analysis of Variance

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Between	7	3.108806	0.444115	14.25*
Between Test Periods	7	3.415134	0.487876	15.65*
Between Positions	7	1.649205	0.235601	7.56*
Residual Error	40	1.246557		
T O T A L	61	9.419702		

* These F values indicate high statistical significance at the 1% level, ie there is less than one chance in a hundred that the variations are not reproducible.

The mean wear loss and relative wear resistance of the tooth compositions are summarized in Table 7. The mean relative wear resistance values should be a rough indicator of the limiting price for any material relative to the price for standard normalized AISI 1080 steel (composition A). In this table the tooth materials are grouped in four, K - C,H,J, - E,D,B, - A. These groupings were determined by overlap of the confidence intervals. The materials in each group are statistically indistinguishable from one another at the stated probability level.

TABLE 7

Mean Wear Loss and Relative Wear Resistance of Tooth Materials

Tooth Material	Mean Wear Loss (gms/hr)	Mean Relative Wear Resistance*	99% Confidence Interval for Mean Wear Loss** (gms/hr)
K	0.1505	5.8	0.0972 - 0.2038
C	0.3560	2.4	0.3027 - 0.4093
H	0.3930	2.2	0.3397 - 0.4463
J	0.4089	2.1	0.3556 - 0.4622
E	0.6224	1.4	0.5691 - 0.6757
D	0.6881	1.3	0.6348 - 0.7414
B	0.7066	1.2	0.6533 - 0.7599
A	0.8711	1.0	0.8178 - 0.9244

* The mean relative wear resistance of a material is the ratio of the mean wear loss of the standard material, A, divided by the mean wear loss of the material being rated.

** The true mean wear loss cannot be determined. The 99% confidence interval has a 99% chance of containing the true mean.

Discussion of Part Two

The data obtained with the cultivator teeth should be applicable to ploughshare points as far as wear resistance is concerned. However, these tests do not give any indication of the relative impact resistance of the various materials. The breakage of the nodular iron point might be an indication of low impact resistance, and indeed it would be expected to be the material with the lowest impact resistance of the ones tested. Actually with the exception of the nodular iron points (composition J), the impact resistance rating of the materials would probably be the reverse to the wear resistance ratings shown in Table 7. Also, again possibly with the exception of composition J, the price of the points would likely correspond with the wear resistance ratings, ie composition K would probably be the most expensive and composition A the cheapest. However, it is not expected that the price of a ploughshare point made to composition K would be 5.8 times the price of composition A, and may, therefore, be cheaper to use in the long run. In the second group it is probable that composition H would be relatively inexpensive. Other factors would have to be taken into consideration, however, before this can be more closely determined.

The poor showing of the hard surfaced points (D and E) was not expected. Examination of these points showed the reason. The hard surfacing material was not wearing appreciably. The main wear was taking place on the mild steel portion of the teeth, especially on the under side of the tooth directly under the hard surfacing material. The photograph in Figure 3 shows this large amount of wear. Possibly a different method of applying the hard surfacing material to attempt to eliminate this excessive wear would show the hard surfacing technique off to better advantage.

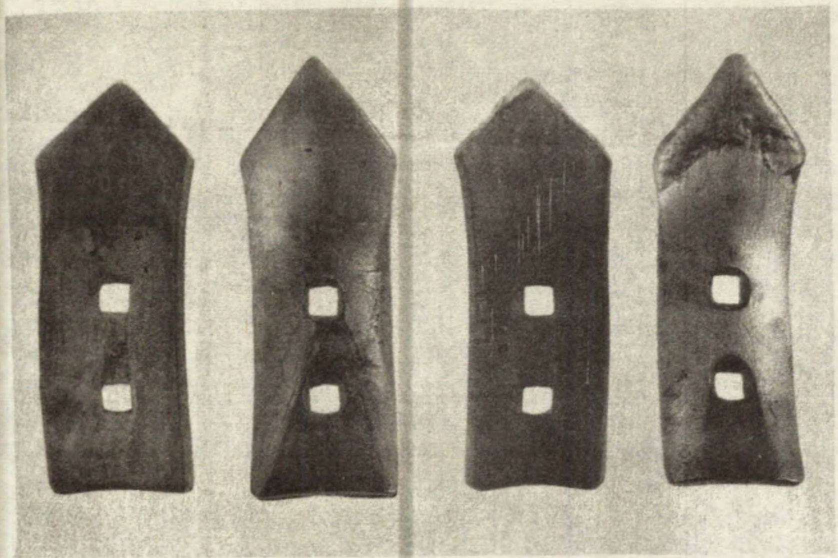


Figure 3. - Photograph of top and bottom surfaces of four cultivator teeth. The two on the left are 5150 steel and 1080 steel quenched and tempered. The next two were hard surfaced. Note the wear on the underside of the hard surfaced tooth.

PART THREE

Proposed Future Evaluation Tests

As previously mentioned in this report, the data obtained to date give some indication as to the relative wear resistance of the various materials to soil abrasion but no data have been obtained on their impact resistance. This, then, would appear to be the next property to investigate and it is first necessary to select the materials for test in this part of the program.

Reference to Table 7 indicates what appears to be a logical basis for selecting materials from the original group of eight. This Table (No. 7), as previously mentioned, shows the materials in four groupings in each of which the materials are statistically indistinguishable at the 99% probability level. It is suggested, therefore, that one material from each group be chosen for use in the next stage of the program, and the materials suggested are K, C, D and A. Composition A would again be used as a standard to which the other three will be compared.

The impact testing part of the tests would be performed at the Physical Metallurgy Division. The suggested method would be to cast a number of the ploughshare points to the required analysis and heat treat them the same way as their cultivator teeth counterparts. These points would then be fixed in a special jig to maintain the share with the tip uppermost. A 50 lb weight would then be dropped onto the tip from varying heights until breakage occurred. The energy absorbed to cause fracture (expressed in foot-pounds) would then be the impact strength of that particular material. At least two points from each composition would be tested in this manner. This, then, would provide a basis for rating the materials from an impact resistance point of view.

The wear testing of the ploughshare points would be done in a similar manner to that used for the cultivator teeth. A four-furrow plough would be used for the tests, one point of each of the four materials being tested at one time. A 4 x 4 Latin Square statistical design would be used. Weight loss per hour would once again be the criterion for the relative wear resistance. The wear pattern could be checked by making a drawing of the outline of each point before and after testing.

The results of these tests should not only produce figures showing the impact resistance and wearing qualities of these materials but also could lay the basis for the testing of different ploughshare materials from time to time.

RKB/RB