O T T A W A June 2nd, 1943.

R E P O R T

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1414.

Metallurgical Research Work on Development of Universal Carrier Track.

(Copy No. 6.)

Abstract

This report is a résumé of the Canadian Bureau of Mines' research and test work on universal carrier track.

The work on the track link is first reviewed. The greater portion of this section of the report deals with aid given in the development of the special Canadian-type blackheart malleable iron link. Some reference is made to work on the cast steel link which is now the only type of link being manufactured in Canada. Test procedures developed for the blackheart malleable link are also outlined.

The second part of this report discusses the work done on track pin development. Procedures followed in the testing of the pin are given. Data on the various types of case hardened pins being manufactured are listed. The development of the homogeneous type pin is outlined.

Bureau of Mines
Division of Metallic
Minerals
-
Ore Dressing
and Metallurgical
Laboratories

CANADA

DEPARTMENT
OF
MINES AND RESOURCES

Mines and Geology Branch

June 2nd, 1943.

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PART ONE. - RESEARCH WORK ON TRACK LINKS.

Introductory:

When the manufacture of universal carriers was first planned for Canada, specifications sent out from Great Britain stated that the track links for these carriers should be made of "whiteheart" malleable iron, case-hardened in a high-temperature cyanide heat treatment.

Although it was subsequently learned that the "whiteheart" malleable had been selected as a track material only because it offered the best production possibilities in the United Kingdom and not because it was regarded as the best material, "whiteheart" malleable, or its equivalent, was insisted upon for the Canadian universal carrier track link; this, in spite of the fact that no whiteheart malleable iron had been manufactured on the North American continent for many years. Because of this insistence and because of the absence of the desired material, the Canadian Bureau of Mines started work which it was hoped would lead to the development of a suitable substitute material. The results of this work are summarized below. Details of experiments on blackheart malleable iron are recorded first, and a short résumé of work done on cast

(Introductory, cont'd) -

steel track follows.

In the work on blackheart malleable the Bureau co-operated very closely with the International Harvester Company of Canada Limited, the firm that eventually went into production of the malleable iron universal carrier link. In working on the cast steel track, the Bureau co-operated with the Hull Iron and Steel Foundries Limited, Hull, Quebec. This firm did not get into production on the universal carrier track, partly because its facilities were taken up with Valentine track production and partly because the Ford Motor Company of Canada undertook to produce the necessary steel tracks. As a consequence, the Bureau's work on cast steel tracks has not been reflected in production. In fact, none of the Bureau's work on track links has had any effect on present universal carrier track production which is all of the Ford cast steel type, malleable iron track link manufacture having been stopped several months ago. The work, however, is of interest, for it allowed for the manufacture of a substitute link during a period when there was not sufficient capacity available for the cast steel link. It is also felt to be of interest because it demonstrates that good results can be obtained from blackheart malleable links and also indicates the possibilities of the cyanided mild steel link.

Because the work is somewhat related, some tests made on cyanided mild steel Valentine track links are also recorded. Finally, test procedures developed in the course of the research work are listed, along with a tabulation of the reports issued by the Bureau on the subject of track links. As the Laboratories functioned as "trouble-shooter" in this field and checked on the quality of goods produced by new manufacturers, some of these reports are of a routine nature. O. D. M. L. reports dealing specifically with development work are: 861, 872, 889, 1050, 1075, 1099, and 1200.

Blackheart Malleable Track Links:

This work was commenced in the spring of 1940. At that time the McKinnon Industries Limited at St. Catharines, Ontario, was attempting to develop a substitute for the British whiteheart link and asked for the assistance of these Laboratories. Tests were made on McKinnon's standard type (short-cycle) iron and on some of McKinnon's links which had been given a special (Promal) treatment by Link-Belt Limited at Toronto, Ontario. This "Promal" treatment consisted of heating the iron to effect sufficient carbon solution to produce a pearlitic structure and subsequently spheroidizing this pearlite. The British link supplied by the Department of National Defence was also examined. The irons investigated had approximately the following analyses:

	McKinnon's iron		British link
	- Per cent -		
Carbon -	2.50*	--	-**
Manganese -	0.29	--	0.26
Silicon -	1.30	--	0.97
Phosphorus -	0.038	--	0.06
Sulphur -	0.095	--	0.179

The British whiteheart link had first been cast "white" in sand and then malleabilized by heating to 950° to 1000° C. while packed in a mixture of new and "spent" iron ore. In this treatment much of the carbon was removed, the residual carbon being either in the pearlitic or temper carbon form. Tests showed that the metal 1/32 inch from the surface of the British link contained 0.68 per cent carbon and the metal in the zone of 1/8 to 3/16 inch from the surface contained 1.27 per cent carbon. Efforts were made to duplicate the British link.

In the first tests the McKinnon links were packed in

* Carbon not determined, as results obtained from malleable iron not accurate.

** As determined on a hard iron sample.

(Blackheart Malleable Track Links, cont'd) -

iron ore. This led to bad scaling. Consequently, as theoretical indications were that the CO_2 gas was responsible for the decarburization, tests were made on the effectiveness of this gas as a decarburizing agent. Fair results were secured, although the decarburization in no case equalled that of the British link.

The decarburized links of the "Promal" type were then given the cyanide treatment recommended in the British specification. This involved holding at 1750° and 50 per cent cyanide for half an hour, air cooling, re-heating to 1475° in weak cyanide solution, and quenching in mineral oil.

The following table lists results of physical tests made on the links:

Sample		HARDNESS Case	HARDNESS Core	Breaking Load, pounds	Bend Angle, degrees
Decarburized McKinnon link, cyanided	-	491	300	15,600	7
"Promal" link	-	278	187	11,200	22
"Promal" link, cyanided	-	571	515	6,700	1
British link	-	481	245	13,600	12

Hardness tests were made using the Vickers method. A 1-kg. load was used in testing the case, and a 30-kg. load in testing the core. Bend tests were made in accordance with the specification, i.e., between 8-inch centres.

It was felt that these tests strongly indicated that the decarburized blackheart malleable link might meet the requirements of the specification. It was pointed out, however, that the "short-cycle" type link was not so suitable a substitute as was the "long-cycle" analysis iron, for the high silicon of the former material made it more difficult both to decarburize and to case. It was recommended that development work be done on a "long-cycle" analysis iron. The "Promal" iron was not satisfactory because in the ordinary heat-treated form it lacked surface hardness, while a case hardening of the "Promal" link

(Blackheart Malleable Track Links, cont'd) -

ruined its properties and made it extremely brittle. The work was of interest in that it indicated that satisfactory decarburization without scaling could be effected in an atmosphere of carbon dioxide.

The work outlined above is covered in O.D.M.L. Report of Investigation No. 872, dated July 26th, 1940.

At this stage of the development the International Harvester Company Limited of Hamilton, Ontario, a manufacturer of "long-cycle" type malleable iron, became interested and a co-operative research which lasted over a year's time was initiated with this company. The first work on International Harvester material was done in the summer of 1940.

The effect of various decarburization procedures was determined. It was found that solid decarburizing agents, consisting of hematite and mixtures of hematite and mill scale, decarburized satisfactorily but also produced a certain amount of scaling. It was also discovered that decarburization could be effected satisfactorily in a mixture of 6 per cent oxygen, 12 per cent carbon dioxide, and 82 per cent nitrogen (produced by burning the gas fuel available), but some scaling was encountered. Carbon dioxide, however, was found to be an excellent decarburizing agent. It was discovered that decarburization by carbon dioxide could be effected in a closed vessel containing CO_2 and iron ore, as the CO produced in the decarburization of the iron by CO_2 was reoxidized by the iron ore present. The decarburized links were given the recommended cyaniding heat treatment and then submitted to physical tests. Various results were obtained, depending on the degree of carburization and on the quality of the casting. In general, the links were found to have a case hardness of approximately 500 Vickers,

(Blackheart Malleable Track Links, cont'd) -

with a core hardness of around 225 Vickers. The above tests gave variable results, the best link having a 12,550-pound bending load with a 10 degree bend, these values being approximately the same as those given by the British-made link.

It was felt that results obtained, which are recorded in O.D.M.L. Report of Investigation No. 889, dated August 29th, 1940, strongly indicated that a satisfactory link could be made from the International Harvester metal. Consequently, arrangements were made to initiate production. A special box-type furnace was erected in the International Harvester plant, for the decarburization of the links in a carbon dioxide atmosphere. In this operation in CO_2 atmosphere, 10,000 links, i.e. approximately 14 tons of metal, are heated to 1700° F. (about 40 hours being required to bring them to temperature), held at this temperature from 40 to 50 hours, cooled to 1400° F. in ten hours, and then cooled from 1400° F. to 1200° F. in 20 to 30 hours.

Links decarburized in this unit were then cyanided in an Ajax-Hultgren immersed-electrode type salt-bath furnace. The cyaniding practice recommended in the British specification was not followed, because it was found to be too difficult to maintain the high cyanide content recommended. The company conducted the casing operation in a 22 per cent "Parkcase" cyanide solution (a barium-containing mixture) at a temperature of 1600° F. The links were heated in a gas-fired unit to just below their critical point before entering the bath, held in the cyanide for 34 minutes, and then transferred to an open holding box in which they were cooled for 35 minutes. They were then introduced into another Ajax-Hultgren unit filled with a low-strength cyanide salt, heated to 1400° F. After being held in this bath for two minutes the links were quenched into the oil

(Blackheart Malleable Track Links, cont'd) -

at around 110° F. The final stage of this heat-treatment operation is rather unique, as the time in the bath is controlled so that the outer skin of the link is heated above its critical temperature while the core of the link remains at a sub-critical temperature. The temperature at which the link goes into the bath has an effect on the time required, the hot link requiring less time in the cyanide than the cold link. It would seem that such an operation would be difficult to control but this has not proved to be the case in practice, as mass-production methods which ensure a standard time for the link in the cooling box and in the final cyanide bath (time in this bath being controlled by feeding the links through the bath on a spiral arrangement) guaranteed the uniformity of heat treatment. The essential metallurgical features of this controlled heat-treatment were developed in the Bureau of Mines laboratories.

Links originally made by the International Harvester Company proved to be satisfactory. However, trouble was encountered when production was increased, many links being rejected by inspection and a great number of the approved links being of the marginal type. During the period from in the autumn of 1940 to the summer of 1941, the Bureau of Mines laboratories co-operated with the International Harvester Company in attempting to overcome troubles encountered. Finally, in the summer of 1941, some time was spent in the Hamilton plant in an attempt to find the source of the troubles and to determine whether some new methods developed in these Laboratories were suited to production conditions. Results obtained in this work are recorded in O.D.M.L. Report of Investigation No. 1050, dated July 12th, 1941. Among other things it was found that

(Blackheart Malleable Track Links, cont'd) -

eye-hole weakness was caused by a high graphite content in the metal at this point and this graphite, in turn, was traced to the use of a graphite-type core wash. The company changed to a silica-type wash and eliminated this difficulty. It was also discovered that the link properties could be improved by double oil-quenching (instead of by normalizing and oil quenching). Good results were also obtained from a link quenched into hot salt. A special type of sub-critical quenching procedure, which is described below, was not found to be suited to International Harvester practice. The company also felt that double quenching would introduce difficulties, as the link would have to be cleaned before entering the second cyanide bath. The hot quenching method was not looked upon with favour, as quenching from a cyanide bath into the nitrate-nitrite mixture would lead to explosions and the use of a caustic hydroxide bath was thought to be dangerous. As a consequence, neither the double quenching nor the hot quenching procedure was introduced.

O.D.M.L. Report of Investigation No. 1075, dated September 25th, 1941, gives in detail the results of experiments on which the summer work at the International Harvester plant was based.

This report outlines the details of the International Harvester practice, giving the heating and cooling cycles of the links in the annealing and heat treatment cycles. It also gives details of the properties conferred by various oil-quenching and draw treatments, and by various austempering treatments. The test work indicated that if the quench-and-draw procedure was to confer satisfactory ductility the draw would have to be at a fairly high temperature, with the result that the case became soft and lacked wear resistance. Results obtained from a link which had been given an austempering

(Blackheart Malleable Track Links, cont'd) -

treatment (which involved a quenching from a cyaniding bath into salt at 600° F.) were excellent.

In the same report are also listed results of tests in which the link was cyanided at temperatures under 1500° F. (a practice which produced a high nitrogen content case), slowly cooled, reheated to a temperature just under the lower critical of the core (approximately 1325° F.), and quenched from this temperature into oil. Under Bureau of Mines laboratory conditions this practice produced a link with quite satisfactory properties, as the nitrogen content of the case lowered its critical point and consequently ensured that it would be hardened from the low-temperature quenching. This quenching temperature, however, merely served as a draw for the core and partially spheroidized its structure.

This treatment, when conducted at the Bureau of Mines laboratories, conferred the following properties: bend strength, 9,500 pounds; degree of bend, 30°; core hardness, 150 Vickers; and case hardness, 500 Vickers. This practice, however, was not suited to conditions such as existed at the International Harvester plant, probably because the composition of the cyanide bath was not such as to produce a high nitrogen case.

At about this time Dr. Genders of the Woolwich Arsenal (England) visited Canada and provided valuable information which would have been of greater assistance had it been available at an earlier date. Dr. Genders stated definitely that the United Kingdom had selected whiteheart malleable iron for the universal carrier malleable links, not because it was regarded as the best material but because it was the only material which would allow for sufficiently large production of

(Blackheart Malleable Track Links, cont'd) -

links under war-time conditions. It was realized that the properties of the links were likely to be irregular and that various manufacturers producing the material would have to be given technical assistance. It was soon found that the white-heart malleable links often stretched in the eye-hole portions due to too heavy a decarburization, that the defects in the castings were accentuated by the cyaniding operations, and that the cyanide layer was rapidly removed in service. Blackheart malleable iron universal carrier links were made and tested but none proved to be successful. In 1939, Ford's at Dagenham initiated production of cast steel links. The steel used was made by mixing molten pig iron and steel scrap in an electric furnace. The resulting steel (designated 7-A) had a carbon content of around 1¼ per cent and consequently required a spheroidizing heat-treatment in order to have sufficient ductility. Such a heat treatment is time-consuming, and some trouble was encountered with the Ford links made from 7-A steel owing to their being improperly heat-treated.

In spite of this United Kingdom experience, Canada was still asked to produce the whiteheart malleable link and when the Campbell, Wyant and Cannon Foundry Co., Muskegon, Michigan, were asked to make cast steel universal carrier links for a British order, it was specified that these links be made from Ford 7-A metal. This latter analysis was only used because it suited British conditions. As Campbell, Wyant and Cannon blew their iron in a Tropenas converter before transferring it to an electric furnace, it was some trouble for them to make such a high carbon material and they could make much more easily a lower-carbon No. 4 material which Ford's had just started to use in universal carrier links. In spite of this,

(Blackheart Malleable Track Links, cont'd) -

numbers of the 7-A steel links were made, and it was not until Dr. Gender's visit that this procedure was altered.

Dr. Gender thought that the practice followed by the International Harvester Company in the manufacture of blackheart malleable links was of considerable interest. He believed, however, that cyaniding of the blackheart malleable casting was not good practice. He believed that all production should be in cast steel and that if blackheart malleable iron were to be used in the links, it should be used in oil-quenched and drawn condition. Bureau of Mines laboratory tests reported above, however, indicated that this procedure would not produce too satisfactory a link.

O.D.M.I. Report of Investigation No. 1099, dated September 27th, 1941, surveys the various types of procedure used at this time in the manufacture of universal carrier links. It lists the properties and manufacturing procedure for white-heart malleable cyanided mild steel, Ford No. 4 steel, and blackheart malleable universal carrier tracks. For the latter material, properties were given for various types of heat treatment. The following table briefly summarizes the values given for physical properties:

Material		Bend Test	Bend, degrees	Core hardness, Vickers	Surface Hardness
Whiteheart malleable	-	12,500	10	155-245 V,5-kg.	500
Cyanided cast steel	-	16,000	25	155-245	640
Ford No. 4	-	18,000	8	275	275(?)
Blackheart malleable I.H. treatment	-	11,000	8	160-275	500
Blackheart malleable austempered	-	12,000	6	295-325	300-400

Four hundred links which had been given austempering heat treatment were tested during the winter of 1942 at Kapuskasing, Ontario. This track was in service for 4,336 miles, and,

(Blackheart Malleable Track Links, cont'd) -

in the words of the user, proved "very satisfactory in every way and gave more mileage and less breakage than other track". These results were regarded as very satisfactory, but as the severity of test conditions was not known it was decided that the test would be duplicated at the Windsor proving ground. Sufficient links for one track were cyanided at 1500° F. for 30 minutes and then quenched into caustic soda at 590° F. to 680° F. The links were held in this fused salt bath for half an hour. These links are now on test at the Windsor proving ground. O.D.M.L. Report of Investigation No. 1200 (dated April 10th, 1942) merely reviews the details of this austempering treatment.

In the fall of 1941, it was discovered that a great many more breakages were occurring in the blackheart malleable links than in the Ford No. 4 links. As a consequence, the International Harvester Company made every effort to improve their practice. On examination it was discovered that the annealing in the box-type, carbon-dioxide-atmosphere furnace was not proving satisfactory, as the links at the top of the furnace and near the gas inlet were not being annealed properly for they contained considerable amounts of pearlite. As a result of this, the combined carbon content of the core became too high in the cyanide treatment, with the result that the link was embrittled. This poor annealing, which was undoubtedly caused by too rapid a cooling through the 1400° - 1200° F. range, undoubtedly would not have occurred had the furnace been properly designed. Provision of additional gas inlets and the reduction of gas supplied in the final stages of the treatment might have cured the trouble. However, the International Harvester Company had additional facilities for the pack-method annealing and found that they could overcome their

(Blackheart Malleable Track Links, cont'd) -

annealing difficulties if the castings were packed in iron ore which had previously been passed through the annealing operation plus 8 per cent of 35 per cent iron ore (the 8 per cent addition being just sufficient to make up for dust loss that occurred in packing). This addition of new ore was just sufficient to produce the desired amount of decarburization without involving scaling. The annealing boxes, each of which contains about 450 links, were placed in the inner portion of the company's ordinary annealing furnace, as it was known that the temperature was under good control in this zone. The castings were then annealed for 168 hours (48 hours to heat to 1400° F., 60 hours to heat from 1400° F. to 1700° F.; 40 hours at 1700° F.; and 20 hours for cooling). After the annealing operation, two links were taken from each box and checked for decarburization by metallographic means. An 0.015-inch decarburization was regarded as necessary. If this was not obtained, the box was returned for re-annealing. This long-cycle annealing operation did not hold up production, as the International Harvester Company had excess annealing capacity. However, company officials were firmly of the belief that annealing in a continuous atmosphere-controlled furnace of the type used by the short-cycle malleable producers would be a much more satisfactory procedure.

The properties of the links were markedly improved by the change in annealing practice. Where previously the average bending strength for the link, as determined between 3-inch centres, was 10,000 pounds, with some links giving as low as 7,000 pounds, the average bending strength under the new annealing conditions was raised to 11,500 pounds with the bending angle being increased from 5 degrees for the old method

(Blackheart Malleable Track Links, cont'd) -

to 9 degrees for the new. Links were also submitted to impact tests, and from November, 1941, to the time the International Harvester Company stopped production, a quite satisfactory grade of link was produced, mainly through the efforts of Mr. T. Rice, superintendent, Mr. McKinney, metallurgist, Mr. H. Davis, metallurgist, and Mr. Ring, company inspector. The production of this blackheart malleable link, however, had been pushed because it was thought that there would not be adequate capacity for small steel castings and when this did not prove to be the case, manufacture of the blackheart malleable link was suspended.

It should not be concluded, however, that the blackheart malleable link was not satisfactory, but rather that the steel link proved to be more reliable.

<u>Experiments on Cyanided Mild Steel Universal Carrier Track Links:</u>

In 1939, when the production of whiteheart malleable type universal carrier link was being insisted on for Canada, and before any experimental production of the cast steel link had started, the Bureau of Mines went on record as believing a cast steel link would give better service. After Dr. Gander's visit in the summer of 1941, it was found that this was also the opinion in the United Kingdom. Early in the war, however, there was no evidence that this was British opinion, as there was a great insistence for the malleable iron link.

In order to demonstrate, however, that a cast steel link could be produced, the Hull Iron and Steel Foundries Limited, at Hull, Quebec, co-operated with the Bureau of Mines laboratories in the production of a cyanided mild steel track link. Before settling on the mild steel track, various alloy

(Experiments on Cyanided Mild Steel Universal Carrier Track Links, cont'd) -

steel compositions were cast in the Bureau of Mines laboratories, the metal for the links being melted in a small 50-pound induction furnace. At that time, those in charge of inspection insisted that the link should have a high surface hardness. Consequently, all links produced were cyanided. Tests made on these cyanided links proved that the mild steel link was the equal of, if not better than, the alloy steel links. As a result of these experiments, Hull Iron and Steel cast sufficient links for the universal carrier and the light Mark II tank. The steel used had the following analysis: carbon, 0.32 per cent; manganese, 0.82 per cent; silicon, 0.29 per cent; sulphur, 0.020 per cent. The links were given the following heat treatment in the Bureau of Mines laboratories: Heat for 40 minutes at 1750° F. in a bath containing 50 per cent sodium cyanide, 30 per cent sodium carbonate and 20 per cent sodium chloride (approximately 1.5 per cent of sodium cyanide was added every hour to keep up the concentration); cool in air to room temperature; re-heat to 1485° F. and hold for 30 minutes in "spent" cyanide bath; quench in oil; and draw at 400° for one hour. The treatment produced the following physical properties:

Bend Load, pounds	Bend, degrees	Surface hardness, 5-kg. load, Vickers	Core hardness, Vickers
14,400	27	644	201

Links so treated were tested in the field. Universal carrier links were pinned with case-hardened SAE 2115 pins manufactured by Canadian Acme Screw and Gear Co. We have no good record of the tests but know that the links went 2,000 miles with an increase in pitch of 4.1 per cent. One link broke in test, due to a casting defect, but the track was reported as being in

(Experiments on Cyanided Mild Steel Universal Carrier Track Links, cont'd) -

exceptionally good condition after a 2,000-mile service. The light tank track was pinned with pins heat-treated in the Bureau of Mines laboratories. These pins were made from SAE 1050 steel, quenched and drawn to approximately 450 Vickers (45 Rockwell C). Again, we have no very good records of the performance of this track, which was tested at Camp Borden, but we do know that after 2,000 miles it showed a pitch increase of only 1.69 per cent. Two links broke in this test but they proved to be faulty castings. These tests are of interest because they show that the cyanided mild steel link will stand up to service loads somewhat more severe than that encountered in the United Kingdom. The tests are also unique in that they were the first in which the homogeneous-type pin was used in the universal-carrier-type vehicle in Canada and it is thought that they were the first in which plain medium carbon steel was proved to be satisfactory for the universal-carrier-type vehicle pin. O.D.M.L. Report of Investigation No. 872, July 26th, 1940, gives details of the physical properties and heat treatments of the cyanided cast steel links.

Following up the success of the cyanided mild steel universal carrier link, a similar type of link was manufactured and heat-treated for the Valentine tank, the object of the work being to develop a link which would be a satisfactory substitute for the austenitic manganese steel link should the manganese supply be curtailed. Steel composition and heat-treatment procedures were approximately the same for the Valentine link as for the universal carrier and light tank link. No preliminary report was made on this work but the track, pinned with case-hardened SAE 2115 pins manufactured by the C.P.R., was tested

(Experiments on Cyanided Mild Steel Universal Carrier Track Links, cont'd) -

in Camp Borden. Complete results of the test are not available, but it is known that the track ran 2,000 miles and was still in quite good condition. In this test the track started with 103 links and finished with 102 links. Original length of track was 37 feet 8 inches, final length of the track 37 feet 11-5/8 inches. The original track weighed 1,583 pounds and the final track 1,546 pounds. Three links cracked and were replaced at the 1,778 mileage. The cyanide mild steel link was never put into production because there was no indication of the curtailment of manganese supplies and also because sufficient facilities for cyaniding were not available.

Test Procedure:

Test procedures for the universal carrier link followed, in the main, those outlined in the original specification. The Bureau of Mines laboratories, however, introduced a test in which the eye-hole was flattened in order to check on the ductility of the casting. This test was quite crude, involving merely the flattening of the eye-hole with a heavy hammer; if cracks developed before the distance from the top of the eye-hole to the bottom of the hole was reduced to one-third, the casting was considered to have insufficient ductility.

In connection with testing, tests developed by the International Harvester Company are of interest. When it was manufacturing the blackheart malleable links, this company required that two links out of every 100 be broken in test. The four guide lugs of these links were required to withstand the 100 ft./sec. blow without fracture. One of the links was then used in the standard 8-inch-centre bending test outlined in the specification. The other links were required to withstand

(Test Procedure, cont'd) -

100 ft./sec. blow on the barrel section. In addition, in each day's production an assembly of 18 links was required to withstand a load of 350 pounds dropping through 36 inches. It was the rigid enforcement of these tests that led to the improvement of the blackheart malleable link and the company deserves considerable credit for introducing tests that were considerably more severe than those specified.

LIST OF O.D.M.L. TRACK LINK REPORTS.

Report of Investigation No.		Date
872	Steel Link, Universal Carrier. (Hull Iron & Steel Foundries, Ltd.)	25/1/40.
861	Experimental Work Universal Machine Gun Carrier, Malleable Iron Track Links. (McKinnon Industries, St. Catharines)	8/7/40.
889	Investigation Work on Universal Machine Gun Carrier, Malleable Iron Track Links. (International Harvester Co.)	29/8/40.
911	Report on Track Links. (International Harvester Co.)	5/11/40.
960	An Examination of a Mark III Tank Track Link. (I.B.U.K. & C.)	8/2/41.
982	An Examination of a Mark III Tank Track Link. (I.B.U.K. & C.)	25/3/41.
1050	Experimental Work on Malleable Iron Universal Carrier Track Links.	12/7/41.
1062	Mark III Track Links. (Tanks Division, M. & S.)	7/8/41.
1081	Examination of a Mark III Tank Manganese Steel Track Link. (I.B.U.K. & C.)	30/8/41.
1075	Report on Malleable Iron Universal Carrier Track Links.	25/9/41.

(Continued on next page)

(List of O.D.M.L. Track Link Reports, cont'd) -

Report of Investigation No.		Date
1099	Survey of Manufacturing Processes, Universal Carrier and Light Tank Track Links.	27/9/41.
1126	Examination of a Defective Valentine Tank Manganese Steel Track Link. (I.B.U.K. & C.)	29/11/41.
1150	Examination of a Broken Churchill Tank Track Link. (A.E.D.B., M. & S.)	3/3/42.
1200	Report on Malleable Iron Universal Track Links.	10/4/42.
1280	Investigation of a Broken Universal Carrier Track Link. (M. & S.)	7/8/42.
1314	Investigation of a Cracked Valentine Tank Track Link. (Request of Dr. C. W. Drury, M. & S.)	9/10/42.
1318	Examination of Track Link, Track Pin and Cotter Pin from a German P.Z. K.W. III Tank. (I.B.U.K. & C.)	21/10/42.
1320	Examination of a High Manganese Steel Valentine Tank Track Link. (I.B.U.K. & C., Req. O.T. 3271)	4/11/42.
1333	Examination of Austenitic Manganese Steel Test Bars and Track Links from the Beach Foundry Limited, Ottawa.	4/12/42.
1342	Examination of a Track Link and Track Pin from a German P.Z. K.W. III Tank. (Mr. Batten, I.B.U.K. & C.)	14/1/43.
1359	Examination of a Broken New Canadian Dry Pin Track Link. (Mr. V.W.G. Wilson, A.E.D.B.)	23/2/43.

PART TWO. - RESEARCH WORK ON TRACK PINS.

Introductory:

At a meeting held in Ottawa on February 15th, 1942, it was reported that Valentine pin failures were occurring in sub-zero temperatures on the Russian front. These Laboratories had previously dealt with Valentine tank pins which had failed in service at early mileages under normal temperature conditions. It was felt that a thorough investigation on pin properties, both at room and at low temperatures, should be undertaken.

Since the universal carrier was being manufactured in Canada it was thought that the 7/16-inch-diameter pin used for this vehicle should be examined in a similar manner. At this time no definite specifications existed to aid the manufacturers in production, other than that for a minimum surface hardness of 700 V.P.N.

Several American manufacturers were producing universal carrier pins for the British government. SAE 3115 was the steel commonly used for these pins. When the nickel shortage developed and the supply of alloys became critical, the British Purchasing Commission was constantly faced with the problem of having to allow the use of other steels instead of SAE 3115. If a proper specification existed, substitutions would have caused no concern; the manufacturer would have been asked to meet the physical requirements of the specification. A satisfactory pin would be assured by the terms of such a specification, notwithstanding the chemical analysis. It was therefore necessary to develop a series of tests and to determine the various physical limits which would give pins

(Introductory, cont'd) -

having the optimum properties in service.

At a meeting held in Toronto on March 16th, 1942, it was reported by the Experimental Wing, Department of Munitions and Supply, Camp Borden, Ontario, that a broken pin occurred for each 1,677 miles traversed by a universal carrier. This figure was taken from their sixteen universal carriers which had travelled 93,901 miles and reportedly broke 56 pins. Results were also obtained on broken pins, from records of universal carriers from Halifax to Vancouver, compiled by the Director of Mechanical Maintenance. 253 universal carriers travelled 403,314 miles, with a reported breakage of 297 pins. This is equivalent to an average of one broken pin for each 1,358 miles.

It was felt that research work should be carried out to develop a pin which would give greater life mileage. Such a pin would have to be reliable in service. It must also be durable, i.e., wear should not be so rapid as to cause excessive increase in the pitch of the track.

Consequently, these Laboratories engaged in a program of universal carrier pin research to:

(a) Increase life mileage of pins.

(b) To produce a more reliable pin.

(c) To develop a satisfactory specification.

Reports which are significant in the research work on this development are listed as follows:

Reports of Investigations Nos. 1224, 1253, 1197, 1251, 1273, 1330, and 1284.

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Test Procedures:

Low Temperature Work -

A temperature of minus 50° F. was chosen as the low temperature in all the physical tests. It was felt that this was the lowest sub-zero temperature that would be reached under actual combat conditions. Before testing, the pins and tools were always kept immersed in acetone and dry ice for half an hour at the testing temperature. This was done in order to be certain that the specimen has attained the bath temperature throughout.

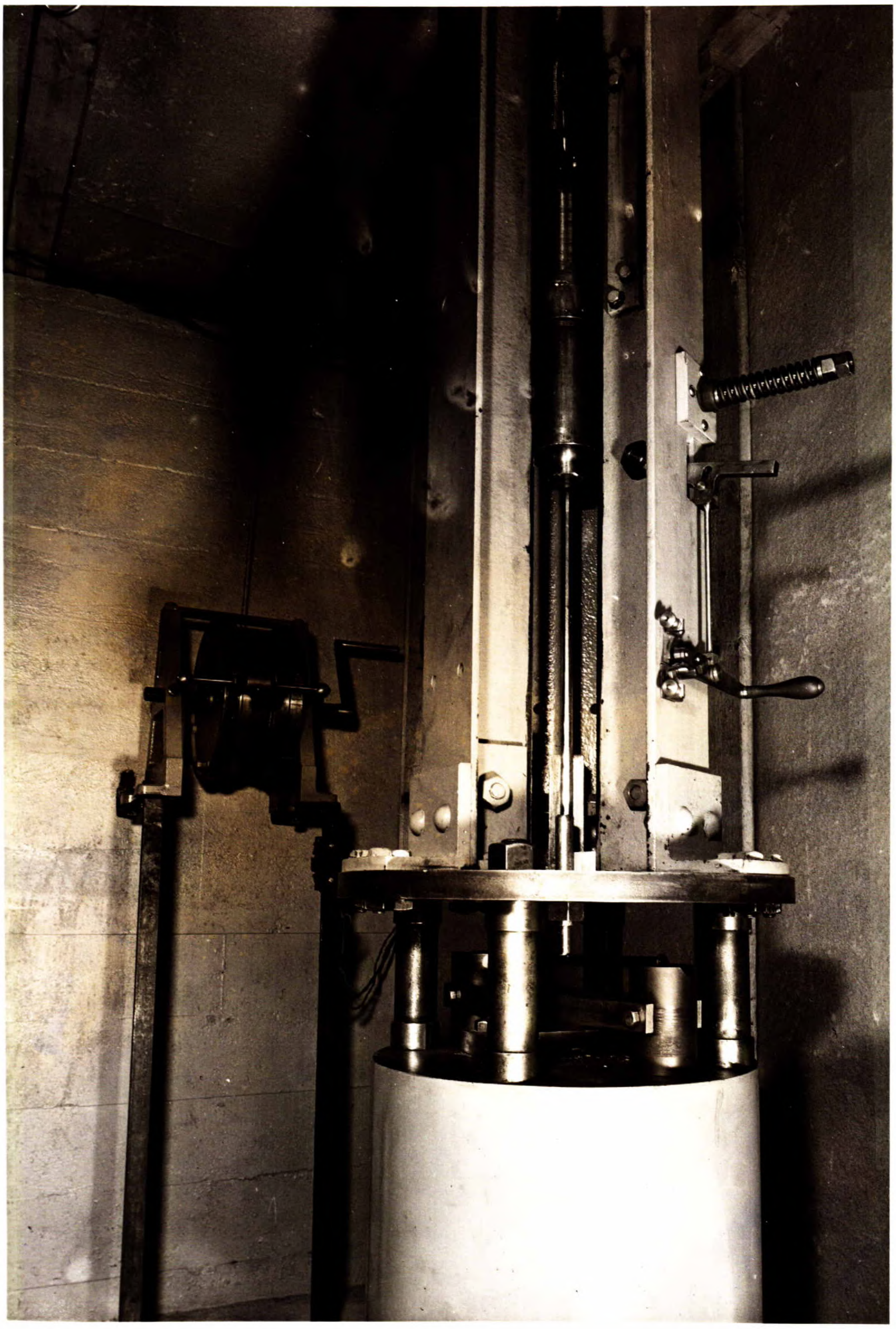
Drop Impact Tests -

This test was used in order to see the reaction of the entire pin to sudden shock. For the universal carrier pin a 5-kg. load was employed. This was dropped from successively increasing height intervals of 25 cm. each, until the maximum height of the machine, 300 cm., was reached. Figure 1 illustrates the machine used.

(Figure 1 follows on Page 23.)
(Text continues on Page 24.)

(Drop Impact Tests, cont'd) -

Figure 1.



DROP IMPACT TESTING
MACHINE USED.

(Test Procedures, cont'd) -

Bend Tests -

Bend tests were carried out on the Amsler Universal testing machine, using a 12-inch radius and 8-inch centres. For the low-temperature work the pins were kept in a bath of acetone and dry ice at minus 50° F. for half an hour before and also during the test. Extensometer readings were taken for each 50 pounds of applied pressure. Charts of increment vs. load were plotted. The elastic limit, permanent bend, and break point were then determined from these charts.

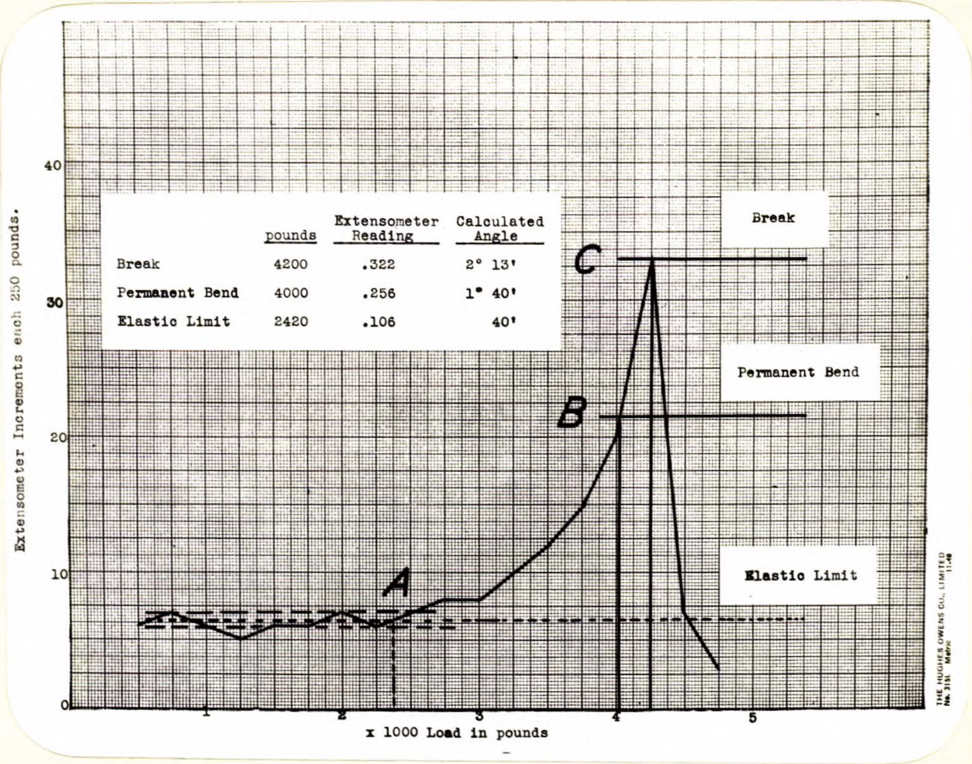
Figure 2 is an illustration of the type of chart obtained. The elastic-limit line is the mean of the two lines drawn connecting the high and low points till the first break upwards in the curve. Permanent bend was arbitrarily chosen to have occurred after a 15-unit increase in increment from the elastic-limit line. The break or first crack of the case is the next definite change in the upward trend of the curve. The deflection, in inches, at each of the above points A, B, and C in the figure can then be obtained from the extensometer readings corresponding to the loads at these points. The angles can also be calculated from the deflection readings.

(Figure 2 follows on Page 25.)
(Text continues on Page 26.)

(Test Procedures, cont'd) -

Bend Tests, cont'd -

Figure 2.



BEND TEST CHART.

THE CASED PIN.

The cased pin is produced by three firms. The treatments employed are shown below:

Allied Products Limited, Detroit, Michigan, has been using SAE 3115 steel. The Chapmanizing process is used for case hardening. In this process anhydrous ammonia is dissociated, then forced into a fused cyanide bath in which the preheated pins are immersed during the period of nitriding. With the ammonia thus activated and introduced into the cyanide bath, it is possible to nitride at temperatures either below or above the critical temperature. At temperatures above 1400° F., the cyanide bath becomes active and case depths of 0.030 inch can be obtained in three or four hours. The treatment employed for the carrier pin is:

(1) Leave pins in the activated cyanide bath for 2½ hours at 1600° F., air cool.

(2) Reheat to 1425° F. and oil quench.

Campbell, Wyant and Cannon, Muskegon, Michigan, carbonitrides SAE 3115 steel for the universal carrier. The treatment of pins in the nicarb furnace is as follows:

The pins pass through 3 heating zones, the first zone being at 1500° F., the second at 1600° F., and the third at 1620° F. The pins are then oil-quenched, reheated at 1425° F., and again oil quenched. The gas mixture is:

150 cu. ft. gas per hour,
80 cu. ft. ammonia gas per hour,
200 cu. ft. raw gas per hour.

Canadian Acme Screw and Gear, Toronto, Ontario, used B.S.S. 5005/102, which is similar to SAE 2115 steel. Chromium

(The Cased Pin, cont'd) -

is optional up to 0.30 per cent. A standard cyanide treatment is employed for case hardening. The pins are heated in Houghton's "Pearliton" for two hours at 1600-1625° F. and then are water-quenched individually in a quenching press.

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A number of broken pins were examined in these Laboratories. Some of these failed early in life, while others lasted well over 2,000 miles. Ninety-five per cent of the pin failures investigated showed evidence of fatigue. A variety of causes were responsible for the other five per cent. Some pins were brittle due to a hard thick case, or to a hard core and medium case; others failed due to a thin case and a soft core.

In the three field tests carried out at Windsor, Ontario, the types of cased pins tested were:

SAE 3115	-	Control pins in all three tests;
NE 8124	-	Hard core (400 V.P.N. approx.);
NE 8124	-	Soft core (300 V.P.N. approx.);
SAE X1020	-	Hard core (400 V.P.N. approx.);
SAE X1020	-	Soft core (300 V.P.N. approx.).

The metallurgical features brought out by these tests were discussed in Report of Investigation No. 1330, dated November 30th, 1942. No conclusions could be drawn from the analysis of both the broken and the unbroken SAE 3115 pins as to a set of physicals which would definitely give a superior pin. All the pins varied in case depth, core hardness, and physicals, ranging from 0.014 to 0.022 inch in case depth and 242 to 442 V.P.N. in core hardness. The following are the core physicals of failed pins with the same case depth:

	3135 miles	3453 miles
Ultimate strength, p.s.i. -	192,400	132,000
Per cent proof stress, p.s.i.	136,000	91,600
Elongation, per cent -	8.5	12
Reduction of area, per cent -	50.0	52

(Continued on next page)

(The Cased Pin, cont'd) -

The core physicals of a pin unbroken at 3223 miles were:

Ultimate strength, p.s.i.	-	192,000
Yield strength, p.s.i.	-	166,000
Elongation, per cent	-	7.8
Reduction of area, per cent	-	40

The results of the NE 8124 and SAE X1020 indicated that a hard-core, shallow-cased pin gave satisfactory service. This type of pin closely resembles a homogeneous pin, since the properties of case and core are fairly similar. Probably, the case is too shallow to have any effect other than the beneficial wearing qualities at early mileages.

It was felt that if a cased pin was to be produced, a case depth of 0.012 to 0.020 inch should be specified in order to ensure satisfactory wear throughout the pin life. For this case depth, the field tests indicated that there was no apparent relationship between core physicals and service. Consequently no core physicals were specified. Although it was realized that a fatigue test would most closely approximate field conditions, no fatigue testing machine was available at this time. As a consequence, laboratory drop impact and bend tests were used to indicate pin quality. Results from these tests appeared to correlate closely with those obtained in service. A number of pins were received from all the pin producers and subjected to these tests. Pins from all firms except one passed a deflection of 0.250 inch, prior to the first cracking of the case. Microscopic examination of the pins which gave a poor deflection revealed that troostite was present at the surface. This troostite, of course, caused embrittlement of the case. The other pins were normal.

After a series of tests, drop impact resistance of

(The Cased Pin, cont'd) -

45 foot-pounds was considered necessary. A firm which had been single-quenching was failing to meet this requirement. A double quench was recommended and a marked improvement was obtained.

SAE X1315 steel was investigated. Twelve pins which had been Chapmanized by Allied Products Limited were subjected to bend and impact tests. The bend deflection was very good, indicating that the elasticity of the case was not adversely affected by the change in steel composition. The impact resistance, both at room and low temperatures, was poor.

SAE 1020 steel was cyanided by holding in the cyanide pot for 1½ hours at 1625° F. and then water-quenching. An examination was carried out on these pins. The case obtained passed the bend deflection of 0.25 inch, but the pins did not have the strength to withstand 45 foot-pounds impact. Troostite was seen around the grain boundaries of the core of these pins and the grain size of the bar stock was 2 to 3. A fine grain size is preferable, and troostite should be eliminated. It is felt that both SAE X1315 and SAE 1020 could possibly be heat-treated to give a stronger pin. Unfortunately, the bar stock was not available to carry out a series of tests. O.D.M.L. Reports of Investigation Nos. 1253 and 1284 (June 24th and August 17th, 1943) discuss the work outlined above.

THE HOMOGENEOUS PIN.

It has always been our opinion that a hard cased surface was unnecessary for the universal carrier pin. It was felt that a quenched-and-drawn pin would be stronger and more

(The Homogeneous Pin, cont'd) -

reliable than the cased pin. The total pitch increase of a track consists of:

(a) Pin wear,
(b) Link wear (in the eyehole), and
(c) Link stretch.

In Canada, a large number of universal carrier steel track links were cast from Ford No. 4 metal. The hardness of the eyeholes was 250-305 Brinell. It was consequently reasoned, and later proved by field test, that the links should wear much faster than the 750 V.P.N. surface hardness pins. Lowering the pin hardness to about 450 V.P.N. then, should not of itself cause excessive total pitch increase.

The homogeneous pin was first tested in Canada in 1940. SAE 1050 steel was quenched and drawn to 450 Vickers (45 Rockwell 'C') and used in conjunction with cyanided steel tracks in the light armoured 6B tank. This test was carried out at Camp Borden, but unfortunately no satisfactory record was kept. However, there is no record of any pin trouble having been encountered and the track was reported to have given good service.

During our investigation on the effect of sub-zero temperatures on track pin properties, some SAE 1045 bar stock, 7/8 inch in diameter, was quenched and drawn to 45 Rockwell 'C'. Laboratory tests, both at room and sub-zero temperatures, were favourable and warranted further examination. More bar stock was received and it was subjected to the same heat treatment as above. The results obtained with this lot were unsatisfactory. The only difference between the pins which were first examined and these latter pins was the grain size. The favourable results were obtained with steel having a McQuaid-Ehn

(The Homogeneous Pin, cont'd) -

grain size of 7, while the unfavourable results were from 3 to 4 grain size stock. No further investigation was made on the SAE 1045 homogeneous pin. It is of interest, however, that some Tocco (induction)-hardened SAE 1045 Valentine pins having 540-570 V.P.N. surface hardness and 0.10-inch case depth gave very good laboratory results. It is felt that a fine-grained, aluminium-killed 0.50 per cent carbon steel could be treated to produce a satisfactory homogeneous pin.

It was thought that SAE 9255, which is a silico-manganese spring steel, would make a satisfactory homogeneous pin. Preliminary tests gave very favourable results. Since this type of pin offered an excellent opportunity for radically improving pin properties, it was felt that further tests should be carried out for the purpose of determining the most satisfactory hardness range within which these pins should be produced. Maximum toughness was desirable without too great a sacrifice in wear resistance.

The heat treatment was carried out in a neutral atmosphere in a Vapocarb furnace. All the pins were held at 1475° F. for half an hour, then quenched in oil at 110° to 120° F. The pins were then given a 40-minute draw treatment. Three different temperatures were employed to produce pins within three ranges of hardness, as follows:

Draw Temperature, degrees F.		Rockwell 'C' hardness range obtained
450	-	55 - 57
700	-	49 - 52
775	-	44 - 47

Pins from 44-52 Rockwell 'C' withstood a total of 700 foot-pounds drop impact from successively higher levels without

(The Homogeneous Pin, cont'd) -

breaking. Low-temperature tests at minus 50° F. duplicated the favourable room temperature results for pins of this same hardness. It should be mentioned that the best drop-impact result obtained at room temperature, for a cased pin up to this time, June 1942, was 90 foot-pounds.

The bend tests showed that the homogeneous SAE 9255 pins take a high load before permanent set. This feature is a great advantage as the ideal pin is one which springs back readily into its normal straight position after impact. Deflections of 0.940 and 1.15 inches were obtained with loads of 2,875 and 2,910 pounds, respectively, before breaking. These pins had Rockwell 'C' hardnesses of 51 and 52. The maximum load for cased pins prior to failing is about 1,500 pounds. This work is outlined in O.D.M.L. Report of Investigation No. 1251, June 23rd, 1942.

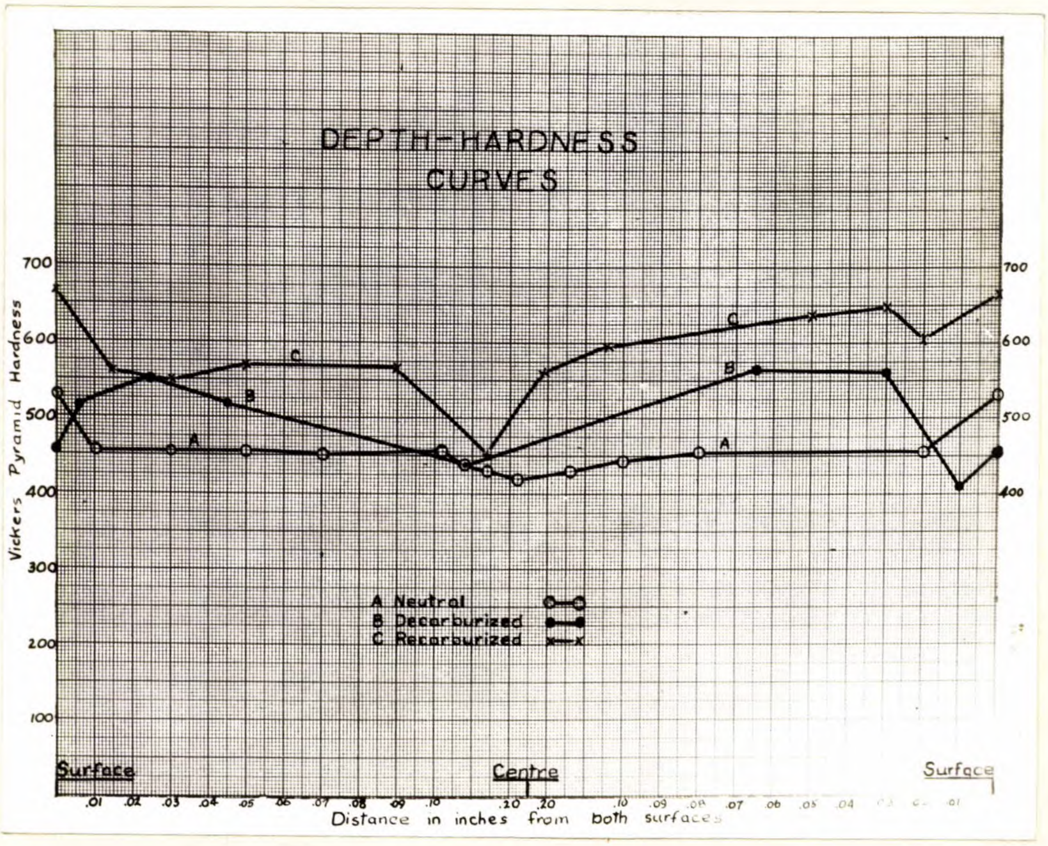
Rolled bar stock usually has a decarburized surface. For a homogeneously hardened pin, this soft layer would wear very rapidly and shorten the life of the track. Since centreless-grinding capacity in Canada was limited, it was necessary to eliminate this decarburized layer by some carburizing treatment. Bars which had been machined to 0.437 inch were then purposely decarburized by an ordinary furnace anneal. These decarburized bars were then recarburized by treating in a Vapocarb furnace, using a carburizing atmosphere.

Some recarburized bars, some decarburized bars, and some bars which had no surface treatment (neutral) were all heated to 1525° F., oil-quenched (110° F.), and drawn at 750° F. The depth hardness curves obtained for a pin of each type are

(The Homogeneous Pin, cont'd) -

shown in Figure 3.

Figure 3.



The Vickers hardness machine and a 10-kilogram load was used for all the hardness values. It can be seen that the decarburization effected was from 0.025 to 0.030 inch in deptth. Recarburization has given a thin skin with a surface hardness well over 600 V.P.N. The neutral pin has a somewhat higher hardness at the surface. This is attributed to the Vapocarb furnace operation; the atmosphere is never kept exactly neutral but slightly carburizing. The properties of the recarburized pin did not differ from those of the neutral pin. Recarburizing not only eliminates the soft surface layer but actually produces a thin skin which should aid the initial wear resistance of the pin. For the SAE 9255 steel, because of the high silicon content, there is no danger that the carbon in the outer surface will become excessively high. The outer case would probably contain

(The Homogeneous Pin, cont'd) -

about 0.60 per cent carbon.

In industry, the plants are using cyanide baths to carry out the recarburization of the bar stock. The Canadian Acme Screw and Gear Company, Toronto, report a 2-point Rockwell increase on the surface due to this treatment. It is felt that this will be quite normal in production. The Cockshutt Plow Company has successfully eliminated a 0.010-inch decarburized stock by heat treatment of 45 minutes in a 44 per cent cyanide bath. O.D.M.L. Reports of Investigation Nos. 1273, 1386, and 1390 discuss all the work on the recarburization of SAE 9255 bar stock. It should be pointed out that recarburizing in a gaseous carburizing atmosphere appears to give much better results than salt bath recarburizing. This latter treatment involves austenitic retention and niyrogen buildup and consequently must be followed by a diffusion treatment in low strength cyanide. The best practice of all for the homogeneous pin, both from the metallurgical and production standpoints, is to centre less grind and heat treat in a low strength bath or nearly neutral atmosphere.

Austempering of the SAE 9255 pins was successfully carried out by quenching from 1625° F. into a salt bath of 47 per cent sodium nitrite and 53 per cent potassium nitrate for 30 minutes at 425° F. The Rockwell 'C' hardness of the pins obtained varied from 52 to 55.5 The drop impact and bend test results compared very favourably to those obtained with the lower-hardness oil-quenched pins. This method produces a pin having higher hardness (which will aid its wear resistance) at no sacrifice to other properties.

Professor John M. Lessels, of the Massachusetts Institute of Technology, recently carried out a number of tests in a track pin fatigue machine which he designed. In a preliminary report issued by Dr. Lessels, it is pointed out that at high stress levels SAE 9255 austempered pins heat treated in these Laboratories to a 600 V.P.N. surface hardness

(The Homogeneous Pin, cont'd) -

are superior to SAE 9255 oil-quenched pins of 571 V.P.N. surface hardness. This latter pin is superior to the standard-production cased SAE 3115 pin having 824/786 V.P.N. surface hardness. The superiority in fatigue of SAE 9255, oil-quenched, over the hard-cased SAE 3115 has already been demonstrated in a field test carried out at Windsor, Ontario. Of 222 SAE 9255 pins tested only three failures occurred up to 4,888 miles. On the same vehicle for the same mileage, nineteen SAE 3115 pins failed out of the original 114 on test. These results suggest that, in a cased pin, fatigue may originate in the transition zone. Discounting the effects of impact on the surface of the cased pin, it would normally be expected that the SAE 3115 pin should have higher fatigue life than the homogeneous oil-quenched pin, since it has a higher surface hardness. The transition zone material of the cased pin is of a lower hardness and a lower fatigue life than the homogeneous pin. The field test results obtained would seem to indicate, therefore, that fatigue failure starts in the transition zone of a cased pin. This hypothesis is further substantiated by the fact that the hard core, thin-cased pins gave better service than the soft core, thin-cased pins, for the transition zones of the former are harder and consequently have higher fatigue life. A series of laboratory experiments is planned to try to establish definitely the mechanism of fatigue failure in the cased pins.

The cooling curves of the SAE 9255 pins were determined, using the 'Speedomax' machine. The thermocouples were attached to the surface of the pins. Figure 4 illustrates the curves obtained for the universal carrier pins, water-quenched, oil-quenched (room temperature and 110° F.), and austempered. Figure 5, of the 7/8-inch-diameter Valentine pins, is included as a point of interest.

(Figures 4 and 5 comprise Pages 36 and 37)

Figure 4.

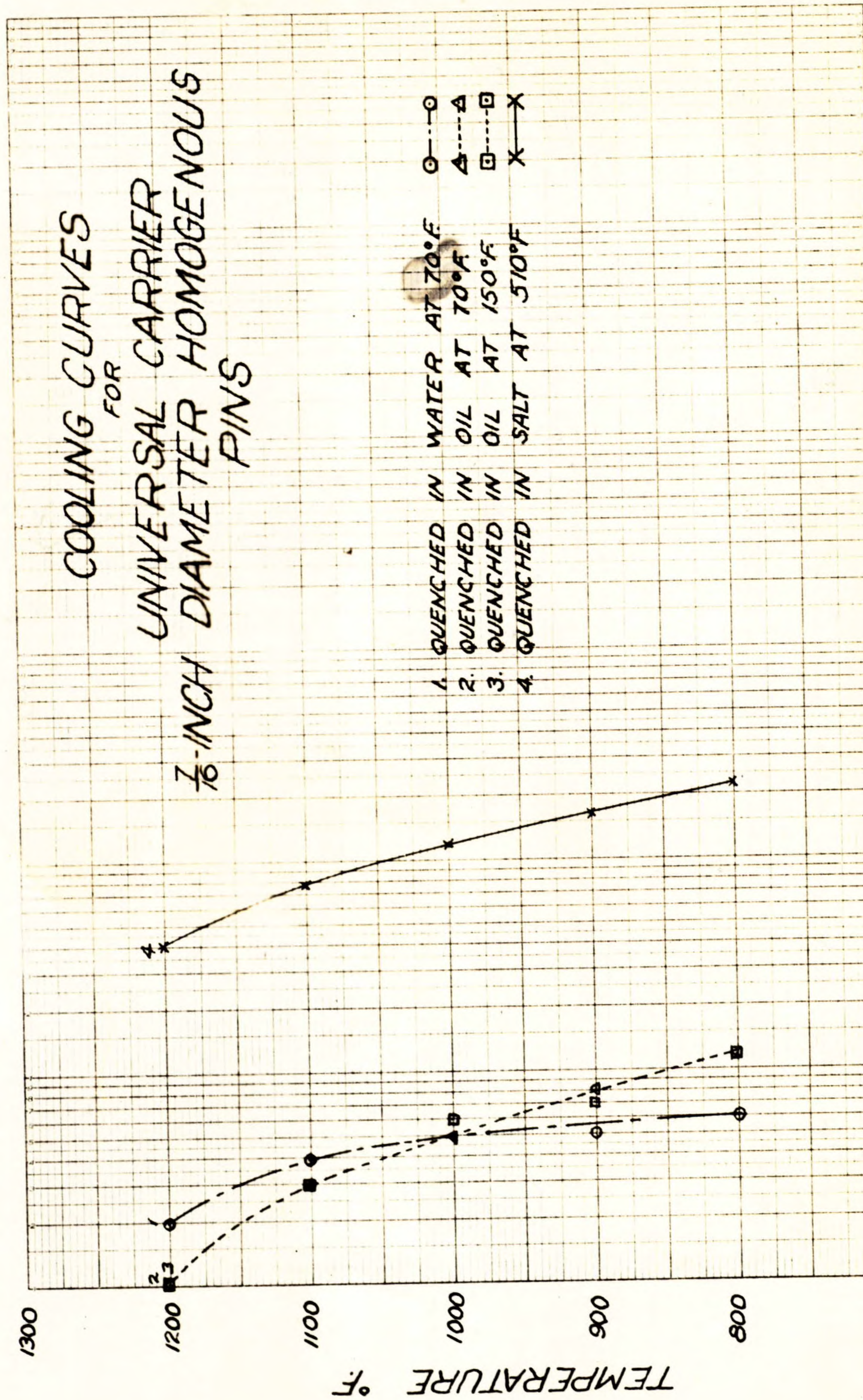
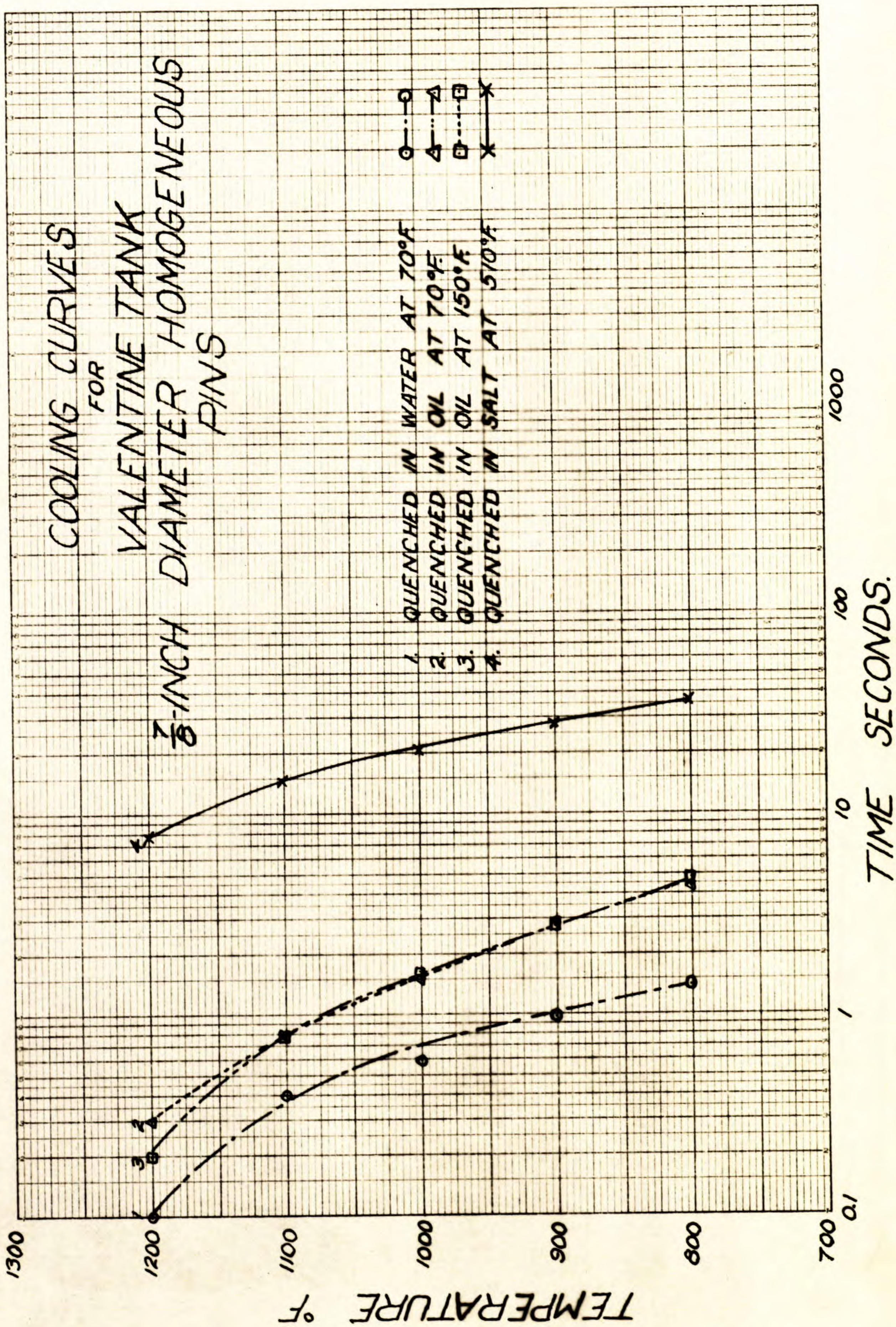

COOLING CURVES
FOR
UNIVERSAL CARRIER
7/16-INCH DIAMETER HOMOGENOUS
PINS
1. QUENCHED IN WATER AT 70°F
2. QUENCHED IN OIL AT 70°F
3. QUENCHED IN OIL AT 150°F
4. QUENCHED IN SALT AT 510°F
TEMPERATURE °F
1300
1200
1100
1000
900
800
700
0.1
1
10
100
1000
TIME SECONDS.
1
2
3
4

Figure 5.


COOLING CURVES
FOR
VALENTINE TANK
7/8-INCH DIAMETER HOMOGENEOUS
PINS
1. QUENCHED IN WATER AT 70°F
2. QUENCHED IN OIL AT 70°F
3. QUENCHED IN OIL AT 150°F
4. QUENCHED IN SALT AT 510°F
0.1
1
10
100
1000
TIME SECONDS.
1300
1200
1100
1000
900
800
700
TEMPERATURE °F

LIST OF O.D.M.L. TRACK PIN REPORTS

Report of Investigation No.		Date
1197	The Effects of Low Temperatures on the Properties of Track Pins. (I.B.U.K. & C.)	2/4/42.
1210	Investigation of Nitrided Track Pins. (C.W. & C.F., Muskegon, Mich.)	29/4/42.
1211	Examination of Broken Universal Carrier Track Pins. (M. & S.)	1/5/42.
1224	Examination of Carbo-Nitrided Universal Carrier Track Pins. (M. & S.)	18/5/42.
1236	Examination of Allied Products Limited Universal Carrier Pins.	1/6/42.
1253	Investigation of SAE X1315 Universal Carrier Pins. (Ford Motor Co. of Canada, Limited)	24/6/42.
1273	Investigation of Decarburized and Recarburized Homogeneous SAE 9255 Universal Carrier Track Pins. (I.B.U.K. & C.)	27/7/42.
1284	Investigation of SAE 1020 Cyanided Universal Carrier Track Pins. (A.E.D.B., M. & S.)	17/8/42.
1297	Investigation of Austempered SAE 9255 (High Hardness, Homogeneous) Universal Carrier Track Pins. (Ontario Steel Products Limited)	9/9/42.
1330	Examination of Universal Carrier Track Pins from Field Tests O-6, 13-W, 16-W, Windsor, Ontario.	30/11/42.
1369	Investigation of Canadian Acme, Screw and Gear Universal Carrier Track Pins. (Dr. Drury, Lot No. 419)	17/3/43.
1386	Investigation of Four SAE 9255 Homogeneous Universal Carrier Track Pins. (Dr. Drury, Lots Nos. 454, 455, 456 and 457)	9/4/43.
1390	Cyaniding of SAE 9255 Track Pins to Eliminate Decarburization. (Cockshutt Plow Company)	22/4/43.

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(Continued on next page)

(List of O.D.M.L. Track Pin Reports, cont'd) -

Report of Investigation No.		Date
1154	An Examination of Tank Track Pins. (I.B.U.K. & C.)	4/2/42.
1170	Examination of English Valentine Tank Track Pin. (I.B.U.K. & C.)	2/3/42.
1229	Examination of Mark III Track Pins. (Campbell, Wyant & Cannon)	21/5/42.
1243	Examination of a Cracked Campbell, Wyant and Cannon Mark III Track Pin.	24/6/42.
1300	Investigation of C.P.R. Pack-Carburized Valentine Tank Track Pins Bent in Service. (Dr. C. W. Drury)	17/9/42.
1318	Examination of Track Link, Track Pin and Cotter Pin from a German P.Z. K.W. III Tank. (I.B.U.K. & C.)	20/10/42.
1342	Examination of a Track Link and Track Pin from a German P.Z. K.W. Mk. II Tank. (I.B.U.K.& C.)	14/1/43.
1359	Examination of a Broken New Canadian Dry Pin Track Link. (Dept. of M. & S., A.E.D.B.)	23/2/43.

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