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OTTAWA April 25, 1945.

REPORT

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1850.

Metallurgical Examination of Copper Trolley Wire.

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(Copy No. 10.)

Bureau of Mines
Division of Metallic Minerals
-
Physical Metallurgy Research Laboratories

CANADA
DEPARTMENT OF MINES AND RESOURCES
Mines and Geology Branch

OTTAWA April 25, 1945.

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Metallurgical Examination of Copper Trolley Wire.

Source of Material and Object of Investigation:

Under date of March 15, 1945, Prof. F. A. Forward, Technical Director, British Columbia War Metals Research Board, The University of British Columbia, Vancouver, B.C., submitted two lengths (approximately 15 inches each) of Copper Trolley Wire for torsion testing in accordance with A.S.T.M. Specification No. B49-39. In addition, seven small specimens were submitted for qualitative spectrographic analysis.

In a letter accompanying the material, Prof. Forward stated that these specimens represented trolley wire purchased by the B.C. Electric Railway Company during the past 15 years, most of it within the past five years. A qualitative spectrographic analysis of these materials was requested in order to determine whether any unusual amounts of impurities might be present.

It was also stated that the trolley wires were failing by fatigue due to surface defects. A copy of the Board's report

(Source of Material and Object of Investigation, cont'd) -

dealing with these failures was enclosed. A method of inspection of a sample of new wire for surface defects was described. This consisted of cleaning a 10-foot length of new wire with a 10 to 25 per cent solution of nitric acid in water, washing with water, and examining. This procedure, if desired, could be carried out on every 50 to 100 feet of wire.

It was admitted that this was a rather tedious method of inspection and suggestions of any other method that would facilitate location of flaws prior to breakage were requested.

Spectrographic Analysis:

A qualitative spectrographic analysis of the samples submittee showed the following elements to be present:

	ELEMENTS			
Sample Number	Major Constituent	Strong Trace	Trace	Faint Trace.
73-2-1	Copper			Mg, Si, Fe, In?
73-2-2	"			Mg, Si, Fe, In?
73-2-3	"			Mg, Fe, Mn, Si, Ca, In?
73-2-4	"			Mg, Fe, Si, Pb, Al, In?
73-2-5	"			Mg, Fe, Si, Pb, Ca, V, Cd, Zn, In?
73-2-6	"		Mg	Fe, Si, Pb, Al, Ca, V, In?
73-2-7	"	V		Fe, Si, Ca, In?
73-2-22	"			Mg, Fe, Mn, Si, Pb, Al, In?
73-2-B	"			Mg, Fe, Si, Pb, Al, Ca, V, Zn, In?
Ottawa Electric Railway, 2/0 Trolley Wire	Copper			Ti, Mg?

MECHANICAL TESTS:

Twist Test -

The two samples marked 73-2-6 and 73-2-7 were tested in accordance with A.S.T.M. Specification B47-39 and withstood nine twists without showing any signs of breakage or surface imperfections.

Tensile and Fatigue Tests -

Specimens machined from the two samples submitted, and also a sample of 2/0 gauge copper trolley wire made by Phillips Electric Manufacturing Company Limited, Brockville, Ontario, for the Ottawa Electric Railway Co., were found to have the following tensile and fatigue properties:

Tensile Test

Sample Marked No.	Diameter of Wire, inch	Diameter of Test Bar, inch	Ultimate Stress, p.s.i.	Elongation, per cent, $4\sqrt{area}$	Reduction in Area, per cent
73-2-6	0.460	0.282	57,400	15.0	54.8
73-2-7	0.460	0.282	56,400	11.0*	55.2
O.E.R.	0.365	0.282	60,000	14.0	50.0
B47-39	0.460	-	49,000	3.75**	-
B47-39	0.365	-	52,800	2.80**	-

* Broke at gauge mark.

** Elongation, per cent in 10 inches.

B47-39 A.S.T.M. Specification for 0.460- and 0.365-inch diameter copper trolley wire.

Fatigue Tests -

Fatigue tests were made by the rotating cantilever method on Krouse high speed fatigue testing machines. Specimens were machined from Sample 73-2-7 from the B.C. Electric and from a sample of 2/0 wire used by the Ottawa Electric Railway Co. The tests were made on solid rotating specimens of the dimensions

(Mechanical Tests, cont'd) -

shown in the following tabulations of results. The machines were operated at a speed of approximately 9,000 revolutions per minute. The endurance fatigue limit was estimated on a basis of twenty million reversals of stress, which was considered to be adequate to determine the comparative fatigue strength of these two samples. The fatigue strength of the B.C. Electric Railway sample was approximately 19,000 pounds per square inch and that of the 2/0 wire used by the Ottawa Electric Railway was slightly less than 20,000 pounds per square inch.

Fatigue Test Results:

"A"

B. C. Electric Trolley Wire 4/0.

Diameter of Test Bar, inch	Fatigue Stress, p.s.i.	Number of Cycles	Remarks
0.225	25,000	1,163,000	Broke.
0.221	20,000	11,016,000	"
0.221	19,500	14,481,000	"
0.223	19,000	+20,000,000	No break.
0.221	18,000	+20,000,000	" "

"B"

Ottawa Electric Railway Trolley Wire 2/0.

Diameter of Test Bar, inch	Fatigue Stress, p.s.i.	Number of Cycles	Remarks
0.180	15,000	+20,000,000	No break.
0.176	16,000	+20,000,000	" "
0.177	17,000	+20,000,000	" "
0.180	18,000	+20,000,000	" "
0.180	20,000	18,862,000	Broke.

Hardness Tests -

The hardness of the three samples was determined by the Vickers method, using a 5-kilogram load. The following

(Mechanical Tests, cont'd) -

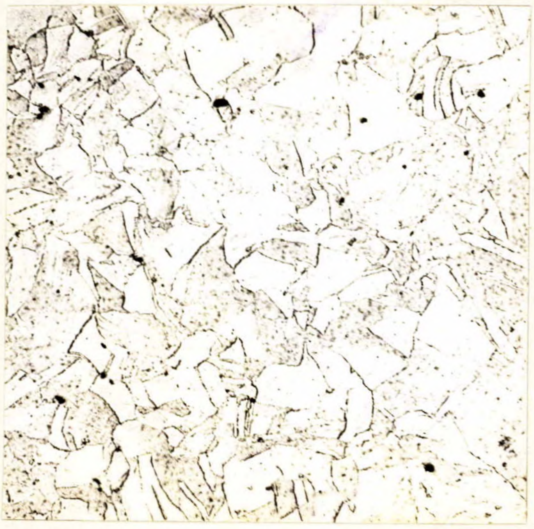
values were obtained:

Sample Number		Vickers Hardness Number
73-2-6	-	124
73-2-7	-	120
O.E.R.	-	124

Microscopic Examination:

Specimens of the wires were mounted in bakelite, polished, and examined under the microscope in the unetched condition. The inclusion content of copper oxide present was considered as average for this type of copper wire. The samples were then etched in an aqueous solution of potassium dichromate. The etched structure of the B.C. Electric Railway wire is shown in Figure 1.

Figure 1.



X500, etched in potassium dichromate solution.

MICROSTRUCTURE OF B.C. ELECTRIC RAILWAY WIRE.

Discussion of Results:

The samples of copper trolley wire submitted had the specified mechanical properties given in A.S.T.M. Specification B47-39 for copper trolley wire. The tensile and fatigue properties compared very favourably with wire used by the Ottawa Electric Railway Co. and manufactured by the Phillips Electric Manufacturing Company Limited, Brockville, Ontario.

A qualitative spectrographic analysis showed only traces of residual elements to be present. However, the number of elements detected was greater in the B.C. Electric Railway trolley wire than in the Ottawa Electric Railway sample.

A microscopic examination showed only a small amount of copper oxide to be present in the two samples examined. The quality present was considered normal for tough pitch grade of copper. The structures were fine grained.

The results of the tests carried out in these Laboratores on the samples submitted indicate that failure of the wires in service was not due to any unusual chemical composition which would adversely effect the fatigue strength of the wire.

Failure, therefore, must have been due to some other cause, such as surface imperfections shown in the B.C. War Metals Research Board's report. These defects would act as stress raisers and lower the fatigue life of the wire.

Failures of this type can be avoided, or minimized, by careful inspection of the wire before it enters service and regular inspection at short intervals in the service life. (See Appendix).

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APPENDIX.

The Inspection of trolley wire for surface defects may possibly be divided into two headings, namely:

I. - Inspection of Trolley Wire in Manufacture.

II. - Inspection of Trolley Wire in Service.

I. - Inspection of trolley wire, either in manufacture or "as received" by the customer, might be carried out by one of the following methods:

(a) Zyglo, a method of inspection of non-magnetic metal parts under black light to detect, by fluorescent indications, significant discontinuities. Manufactured by Magnaflux Corporation, 5908 Northwest Highway, Chicago, Illinois, U.S.A.

(b) Electronic Equipment. Sperry Electric Flaw Detector for the inspection of ferrous and non-ferrous bar stock.

(c) Cyclograph. Reference of application can be obtained from Ontario Research Foundation, Toronto, Ontario.

II. - Inspection of trolley wire in service is generally carried out by a visual inspection of the line, preferably at night, using an elevated truck and a spotlight. This method has been found to be quite satisfactory by a number of traction companies.

The following information was submitted by the Northern Texas Traction Company, Fort Worth, Texas, and is the method of inspection now in successful operation by the Ottawa Electric Railway Company, Ottawa, Ontario.

"Periodic inspections are made of each line at least every three months. This is a general inspection and includes testing of lightning arresters and grounds, inspection of span wires, feeders, poles and fittings. This inspection is made during the day. A weekly inspection is made of trolley wire frogs and

(Appendix, cont'd) -

other trolley special work. This latter inspection is made at night by a trouble crew, of two men, which is on duty until 1.00 a.m. For this inspection a portable automobile spotlight is supplied to the man on top of the tower truck who gives the wire and fittings a very close examination as the truck travels along the track at about four miles per hour. The use of this spotlight permits a much closer and thorough examination than inspection made by daylight, when the inspector must look at the wire against a bright sky.

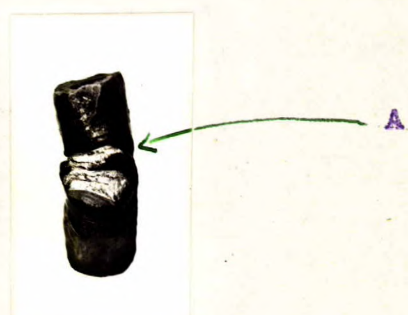
"Interruptions to service have been reduced by these systematic inspections and they have more than paid for themselves by catching trouble before serious damage was done."

A weekly inspection is carried out by the Ottawa Electric Railway of the trolley lines in the downtown area. Figures 2 and 3 are photographs illustrating a fatigue failure spotted on one of these weekly inspections.

Figure 2.

AS REMOVED FROM TROLLEY LINE.

Figure 3.



FRACTURED WIRE OPENED UP TO SHOW THE START OF THE FATIGUE CRACK AT A.

(Approximately to size).

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