O T T A W A December 9th, 1943.

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of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1551.

Preliminary Report on the Effect of Cooling Rate on the Physical Properties of 4- to 12-mm. Armour Plate.

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Introduction:

Recently, Dr. C. W. Drury, Director of Metallurgy, Army Engineering Design Branch, Department of Munitions and Supply, Toronto, Ontario, requested (Requisition No. 706, Report No. 12, Test 4) that a program of research on cooling rates and their effect on armour properties be started.

Since it had been shown in previous investigations that physical properties are very dependent on the rate at which the steel is cooled from the hardening temperature, it was decided to attack the present problem from this angle. The first data required were those which would give the cooling rates obtained in the production treatment of armour plate. Accordingly, the Shurly-Dietrich-Atkins plant in Galt, Ontario, was visited and tests were run on armour plates 4-, 5-, 6-,

(Introduction, cont'd) -

7-, and 10-mm. thicknesses, to determine the cooling rates.

At the Shurly-Dietrich-Atkins plant, two quenching methods are used. In one method the plates are transferred from the furnace to a press and squeezed between water-cooled platens. Small pieces of plate, of similar thickness as the plate being quenched, are placed in the press to "shim up" the platens and allow even pressure distribution during quenching. Pressure is transmitted to the platens, which are 42x90 inches, by two pistons 36 inches in diameter. Thus the pressure on the plate depends on the area of the platens which is covered by plates. Pressure on the pistons is normally 2,000 pounds per square inch, but it may be varied somewhat. Table I shows the pressure on the plate being quenched with various pressures on the pistons and various amounts of the platen area covered by the plates.

TABLE I.

Part of platen area covered	Pressure on pistons - lb./sq.in.		
	2,000	1,300	185
	-(Pressure on plate, lb./sq.in.)-		
Totally covered	1,075	700	99.5
¾ covered	1,430	930	132
½ covered	2,150	1,400	199

In the second method the plates are quenched in water. The plates are removed from the furnace, held vertically in a press, and the whole fixture lowered into a water tank. The press is made up of bars spaced about six inches apart to allow the water to get at the plates. It is so constructed that the minimum plate size it will hold is 36x18 inches.

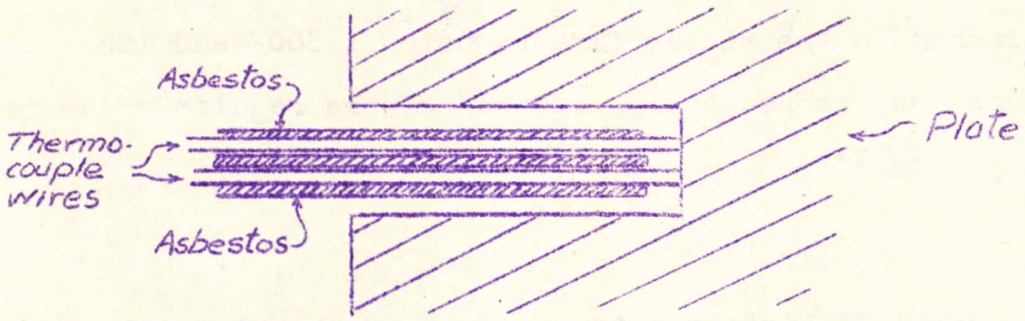
PROCEDURE:

The Speedomax recorder, manufactured by Leeds and Northrup, was used to determine the cooling rates. The method of attaching the thermocouple wires to the plate is shown in Figure 1. A slot about four inches deep was cut in the plate and the wires were welded to the bottom of the slot. The

(Procedure, cont'd) -

wires were wrapped in asbestos tape for a distance of about a foot from the plate.

Figure 1.



METHOD OF ATTACHING THERMOCOUPLES TO ARMOUR PLATE.

To determine the cooling rate in the platen fixture the experimental plates were placed in the furnace and left there for the regular production cycle, which is from 40 to 50 minutes, depending on the plate size, at a temperature of 1600° to 1650°F. They were then quenched in the regular manner in the press.

For the water quench, the press is constructed such that the minimum plate size it will hold is 18x36 inches. Since the experimental plates were smaller than this, the press could not be used to hold them. However, it was found that 12 seconds were required from the time the plate was removed from the furnace, to place it in the press, close the press, and drop the whole fixture into the water. So the experimental plates were removed from the furnace and held above the water for 12 seconds before quenching them.

In these ways, cooling curves were obtained for quenching 4-, 5-, 6-, 7-, and 10-mm. plates in the platen fixture and in water. These curves are shown, plotted on semi-logarithmic paper, in Figures 2 and 3. Figure 2 shows the curves for all sizes tested, when quenched in the platen fixture, and Figure 3

(Procedure, cont'd) -

the curves obtained for similar sizes when water-quenched. Figures 4 and 5 show the cooling curves obtained on 10-mm. plate quenched in the platen fixture using 1,300- and 185-pound pressures, respectively, instead of the regular pressure of 2,000 pounds.

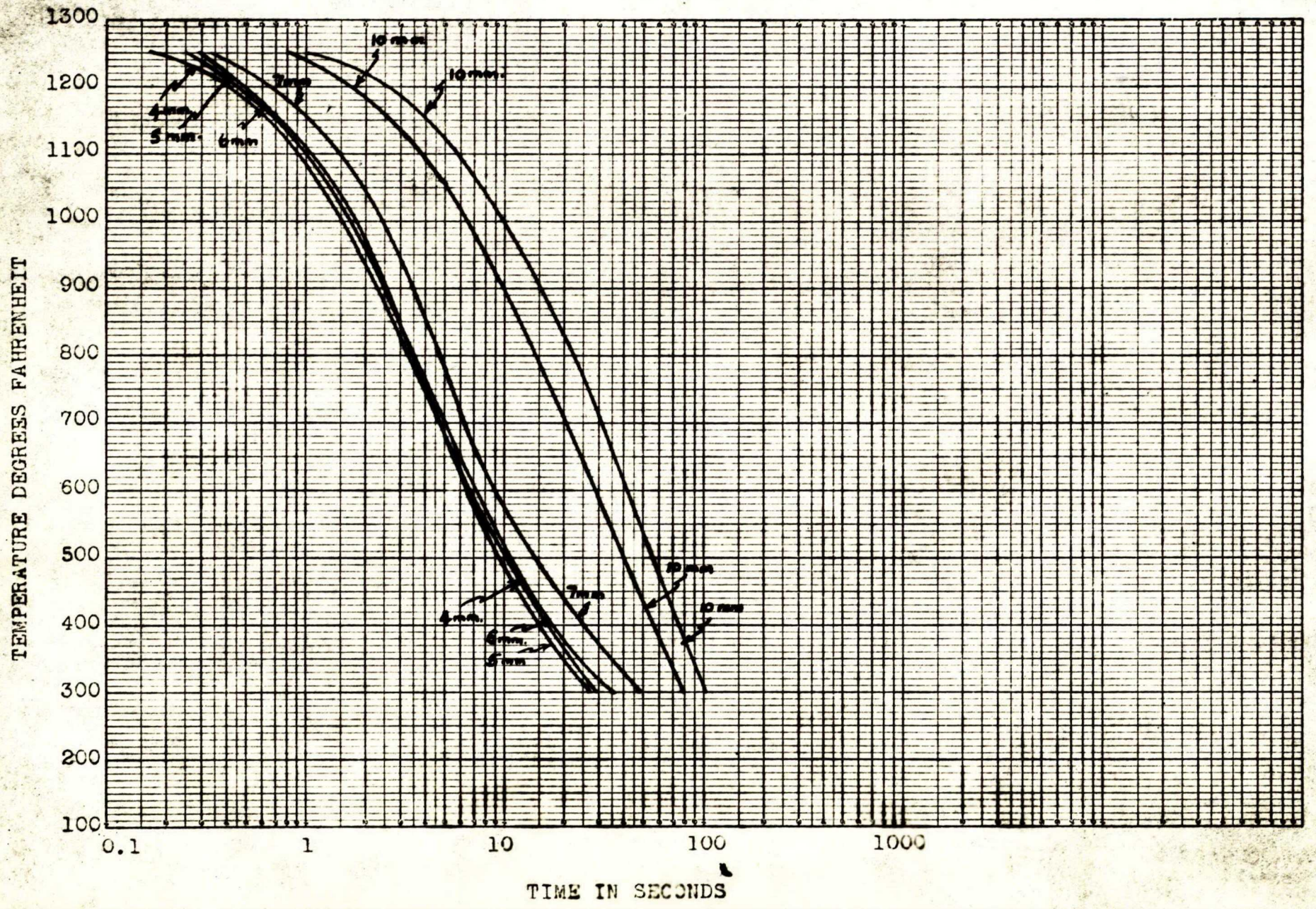
Results:

Table II lists the temperature of the plates in the furnace, the temperature of the plates at the start of the quench, the temperature drop during the transfer from the furnace to the quench, and the cooling rate at 1300° F.

TABLE II.

Size of plate, mm.	Type of quench	Temperature in furnace, ° F.	Temperature at start of quench, ° F.	Temperature drop, ° F.	Cooling rate at 1300° F., ° F./sec.
4	Platen	1650	1450	200	236
5	"	1620	1480	140	187
6	"	1640	1460	180	205
7	"	1600	1475	125	149
10	"	1640	1485	155	62.5
4	Water	1605	1355	250	735
5	"	1615	1435	180	456
6	"	1615	1385	230	535
7	"	1600	1475	125	362
10	"	1580	1485	95	241
10	Platen, 1300 pounds piston pressure	1600	1485	115	16
10	Platen, 185 pounds piston pressure	1605	1540	65	15

Figure 2.



COOLING RATES OBTAINED ON VARIOUS SIZES OF ARMOUR PLATE QUENCHED IN THE PLATEN FIXTURE

Figure 3.

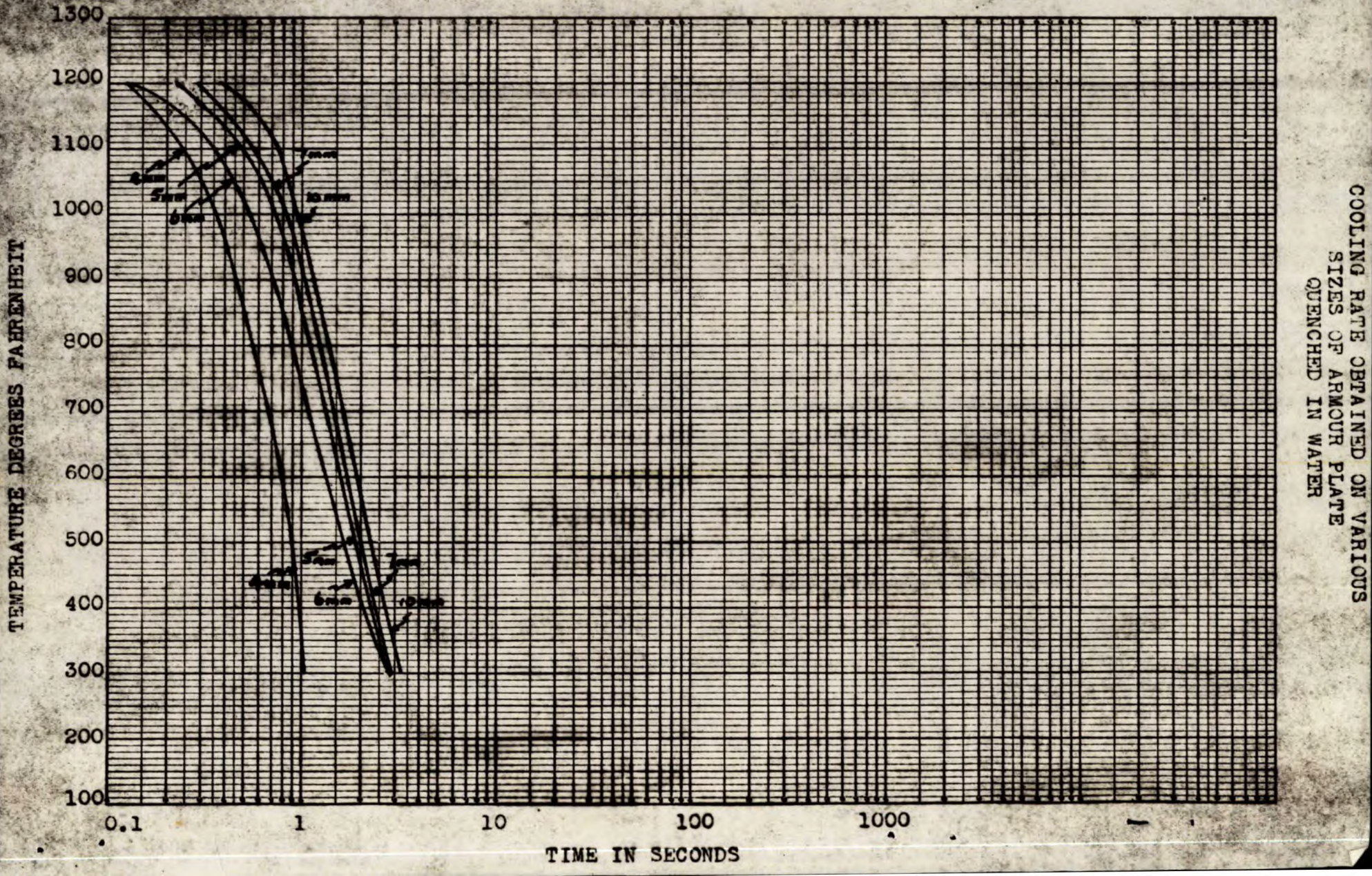
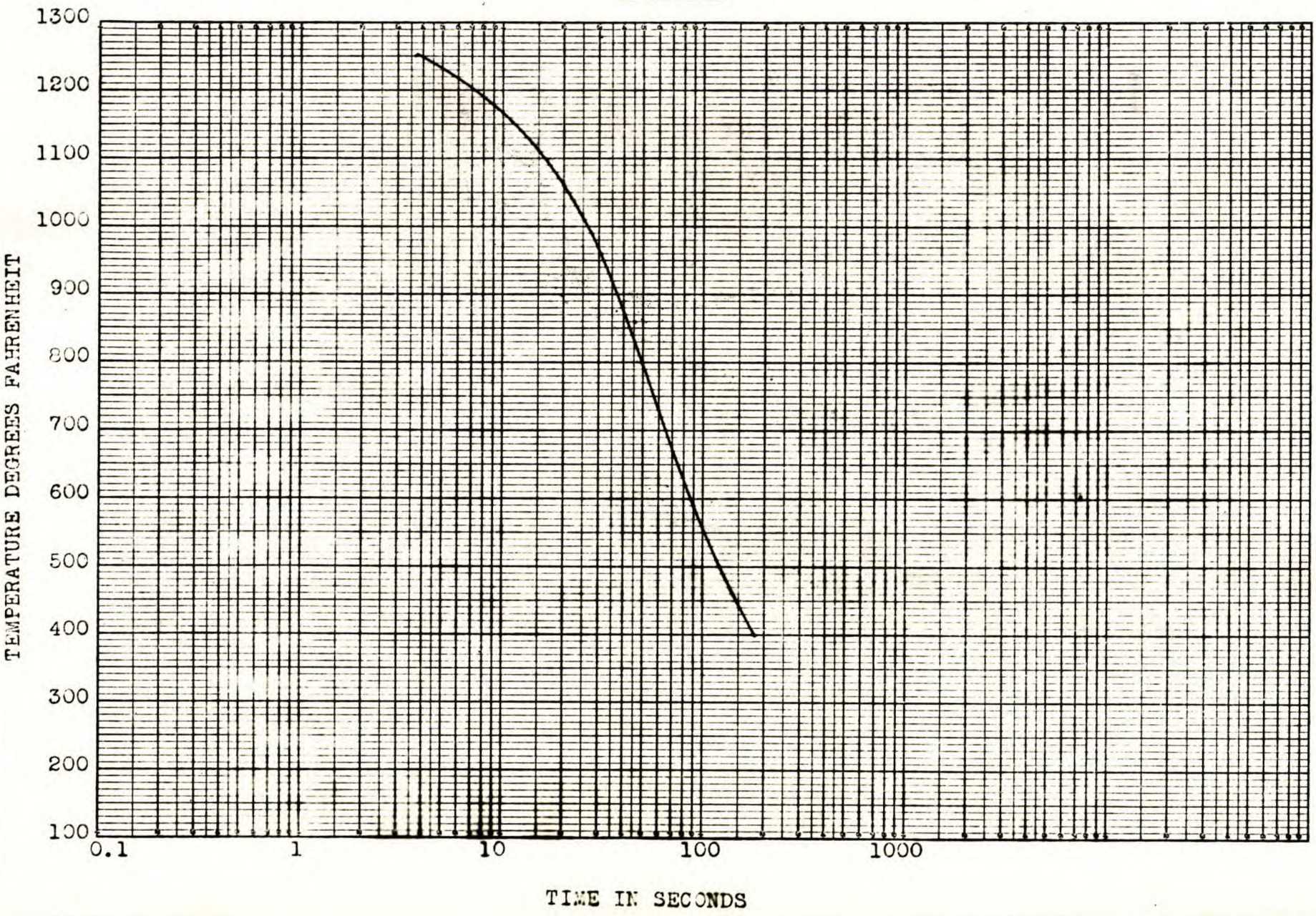
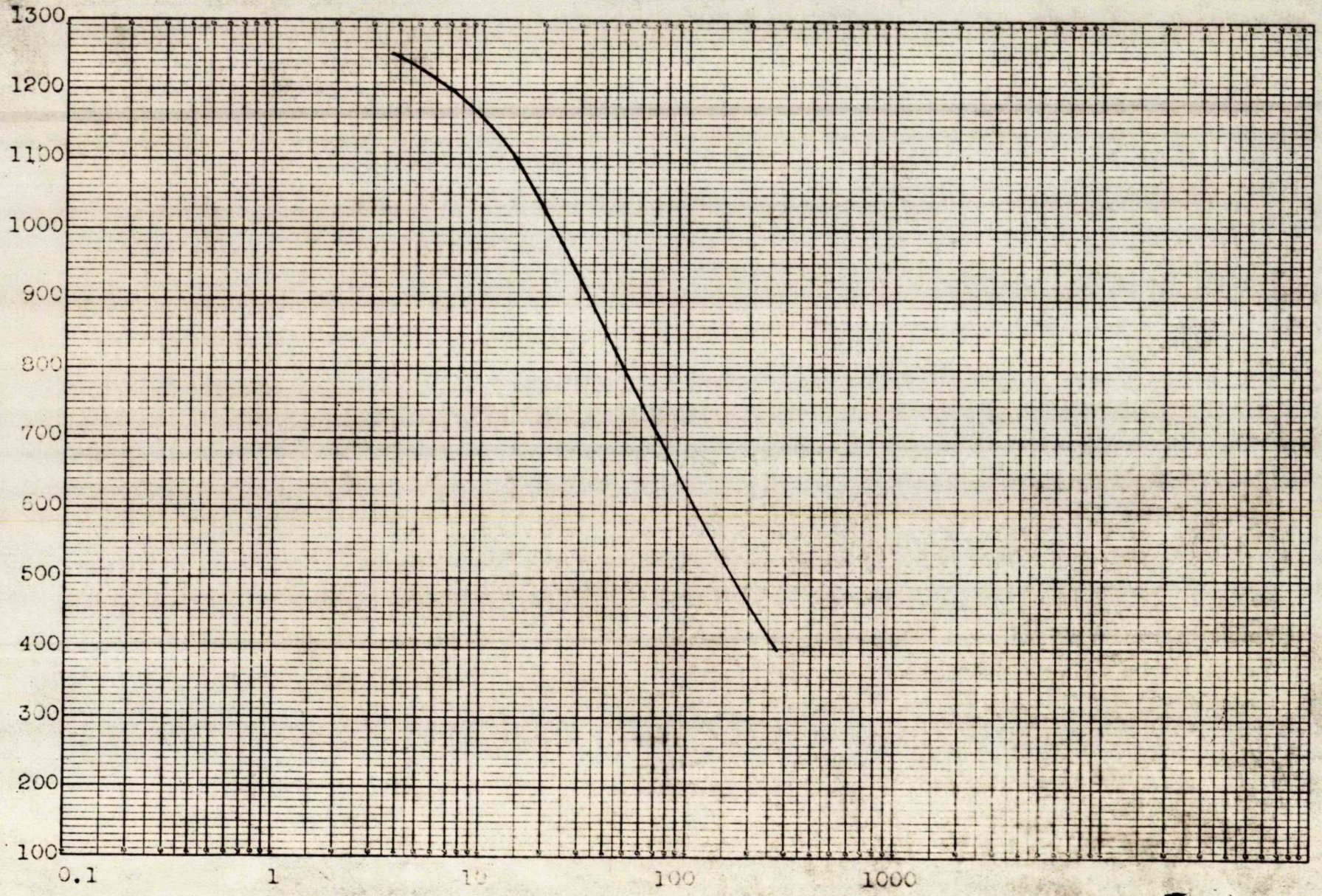

1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
TEMPERATURE DEGREES FAHRENHEIT
0.1
1
10
100
1000
TIME IN SECONDS
COOLING RATE OBTAINED ON VARIOUS
SIZES OF ARMOUR PLATE
QUENCHED IN WATER

Figure 4.



COOLING CURVE OBTAINED ON 10 LBS. ARMCO
PLATE QUENCHED IN THE [illegible]
1300 LBS. [illegible]

Figure 5.



COOLING CURVE OBTAINED ON 10 GA. ARMCOUR
PLATE QUENCHED IN THE PLATEN FIXTURE
185 LBS. PRESSURE

Discussion:

Before commenting on the curves obtained, some remarks on the process at the Shurly-Dietrich-Atkins plant are in order.

Considering the platen quenching first, the plates are transferred manually from the furnace to the platen fixture. Usually, two plates are quenched at once. The first plate is removed from the furnace and placed between the first and second platens. The second plate is then taken out and placed between the second and third platens, and the platens are closed. The furnace door remains open about a foot during the whole operation. Thus, the time between removal from the furnace and start of quench is longer for the first plate than for the second. This difference is from six to eight seconds. Therefore the first plate is colder at the start of the quench than the second plate, and if it has cooled to such a degree that its cooling-curve cuts the "nose" of the S-curve for the steel, complete hardening will not take place. However, the results of hardness tests taken as a production check do not indicate any lowering of hardness on these plates, so it may be assumed that the steel used has sufficient hardenability so that, on cooling, the cooling curve does not cut the nose of the S-curve.

In the case of the water quench, only one plate is quenched at a time. As mentioned previously, the plate must be a minimum of 36x18 inches to fit into the press. It is transferred manually from the furnace to the press, the press is closed, and the whole fixture is lowered into a water tank in which the water is circulated by a pump.

Very little can be said about the shapes of the cooling curves, as there is no data to compare them with. From Table I

(Discussion, cont'd) -

it will be noted that in both the platen quench and the water quench the 6-mm. plate has a greater cooling rate at 1300° F. than has the 5-mm. plate. With this exception, the cooling rates decrease quite regularly as the size of plate increases. The cooling rate obtained on 10-mm. plate, using pressures of 1,300 pounds and 185 pounds, is lower than that with the full pressure of 2,000 pounds, as is to be expected.

The temperature drop of the plates during removal from the furnace and placing in the platen fixture shows the variation in the time required to transfer the plate. In the case of the water quench the temperature drop shows more regularity, indicating that the times required to quench the plates are more uniform. If the test plates had been actually quenched in the press the times might well have been more irregular, but numerous timing trials on production plates showed the time to be quite regular.

Further Investigation:

Now that the production cooling curves have been obtained, the program for further research is to duplicate these cooling curves in the laboratory and to obtain other cooling rates both faster and slower than these. Thus a whole series of cooling curves for each plate thickness will be obtained. The physical properties of test specimens cooled at each rate will be determined and the results plotted. From these charts, the cooling rate at which the physical properties begin to drop off will be found. If this cooling rate is lower than that obtained in production, then the optimum physicals are being obtained in production: but if it is greater, then the production cooling rate must be increased, in order to obtain optimum physicals.

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