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# LABORATORY

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## EFFECT OF TEMPERING TREATMENT UPON PHYSICAL PROPERTIES OF MARTENSITE TEMPERED TO A FIXED HARDNESS.

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Watertown Arsenal Laboratory Memorandum

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# EFFECT OF TEMPERING TREATMENT UPON PHYSICAL PROPERTIES OF MARTENSITE TEMPERED TO A FIXED HARDNESS

## Object

To study the effect of various tempering treatments producing the same hardness upon the other physical properties of tempered martensite.

## Abstract

Samples of martensitic SAE 1095 have been tempered to Rockwell C 30 and to Rockwell C 40 using tempering times of 5 minutes to 17 hours and corresponding temperatures. The tensile properties at each hardness were found to be the same for all tempering treatments. Samples of martensitic SAE 4140 were tempered to Rockwell C 22½ using times of 15 minutes to 16 hours. V-notch Charpy impact properties at -195° C. to +20° C. and tensile properties at room temperature were found to be essentially the same for all tempering treatments.

## Introduction

In a previous study* relations were developed between the temperature and the time necessary to temper a steel to a fixed structure as determined by hardness. There seems, however, to be no reliable evidence as to whether specimens of a steel having the same tempered structure as determined by hardness (and structure prior to tempering) are also equal with respect to all tensile and impact properties. It is known, of course, that this is not true for the impact properties if temper brittleness or

*J. H. Hollomon & L. D. Jaffe, "Time-Temperature Relationships in Tempering Steels". A.I.M.E. Tech. Pub. No. 1831. Metals Technology 12, No. 6, Sept. 1945.

retained austenite effects are present. Neither would identical properties be expected, in steels showing marked secondary hardening, for samples tempered below and beyond the secondary hardening maximum. It was the purpose of the present study to determine whether in other cases specimens of a martensitic steel have the same properties when tempered to the same hardness using different combinations of tempering time and tempering temperature.

## Experimental Work

### SAE 1095 Steel

Commercial SAE 1095 bar stock of the following composition was obtained in the form of 3/4 inch hot-rolled rounds.

| C | Mn | Si | S | P | Ni | Cr | Cu | Mo | V |
|---|---|---|---|---|---|---|---|---|---|
| .98 | .30 | .30 | .021 | .007 | .Tr | .03 | .055 | nil | nil |

The bars were given a normalizing treatment consisting of 1 hour at 875° C. followed by air-cooling. They were then machined to 7/16 inch diameter blanks, each long enough for one tensile specimen. The blanks were austenitized 1 hour at 870° C., and quenched in cold brine. The quench was followed within a few minutes by cooling to about -70° C. in dry ice and alcohol in order to minimize retention of austenite. A metallographical examination of a quenched blank indicated that the bar had been fully hardened to martensite. No undissolved carbides were found.

Preliminary tests were made to determine combinations of tempering time and temperature that would yield hardnesses of 40 Rockwell C and of 30 Rockwell C*. On the basis of these preliminary tests, tempering treatments of 5.3 minutes at 548° C., 52.8 minutes at 482° C., and 17.6 hours at 415° C., were selected as producing a hardness of 40 Rockwell C. To produce 30 Rockwell C, the following tempering treatments were selected: 5.3 minutes at 652° C., 52.8 minutes at 580° C., and 17.6 hours at 505° C. Three quenched blanks were given each of these tempering treatments. Molten lead was used as the tempering medium for temperatures above 500° C. and molten salt for temperatures below 500° C.

Two of the blanks from each treatment were machined to standard .252 inch tensile bars. One of these specimens was tested in tension in the usual way, while the other was used for determination of the stress-strain curve for flow in simple tension. (The stress-strain curve was determined by making simultaneous measurements of load and diameter while the specimen was pulled in tension, and computing the true stress and true

*This work was carried on prior to the completion of the investigation establishing the general relationships between time and temperature for tempering.

strain from these measurements.) Results are shown in Table I. In one case, a cold-shut was found in the fractured bar and a duplicate test was, therefore, made, using the third of the blanks given that tempering treatment.

## Steel SAE 4140

SAE 4140 of the following composition was obtained in the form of cold-drawn bars:

| C | Mn | Si | S | P | Ni | Cr | Mo |
|---|---|---|---|---|---|---|---|
| .36 | .72 | .32 | .028 | .012 | .30 | 1.00 | .21 |

Preliminary tests indicated that this steel would harden to martensite in a size large enough for standard Charpy specimens. 5/8 inch round blanks were, therefore, austenitized 1 hour at 870° C., quenched in water, and stress-relieved by holding in oil for ½ hour at 150-200° C. Preliminary measurements were made of the hardness obtained with 1 hour tempers at various temperatures. On the basis of these results, and of the paper of Hollomon and Jaffe mentioned above, the following tempering treatments were selected as providing a hardness of Rockwell C 22½: 15 minutes at 704° C., 1 hour at 675° C., and 16 hours at 618° C.*. Quenched blanks were given each of these treatments, using lead for the tempering medium, and then quenched to room temperature. Standard .357 inch tensile bars and standard V-notch Charpy bars were machined from these blanks. The tensile bars were tested at room temperature with results indicated in Table II. The Charpy bars were tested at +20°, -80°, and -195° C. The results are indicated in Table III. Several bars were found after testing to have been cracked, while one was struck off-center in the testing machine. These specimens were replaced by others.

## Conclusions

It will be seen from Tables I to III that there are no significant differences between the properties found for the different tempering treatments that gave the same hardness. Thus, it appears likely that specimens of a martensite tempered to the same extent as indicated by hardness do have the same mechanical properties and so, presumably, essentially the same distribution of carbide particle sizes.

Note: After the manuscript of the above report was completed, a

*It was found impractical to use two hardness levels because of the danger of forming austenite at temperatures above 705° C., and of producing temper brittleness at temperatures below 600° C.

report of Snodgrass* came to the authors attention. Snodgrass studied presumably slack-quenched specimens of 1045, 2340, and 4140 steels. On 1045 (which is not temper brittle**) the same tensile and impact properties were obtained with three tempering treatments giving the same hardness. On 2340 and 4140 the tempering treatments were such that temper brittleness developed. As would be expected***, the tensile properties for each of these steels were again the same when the hardness was the same, but the impact properties were lower the lower the tempering temperature and the slower the cooling from this temperature.

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*T. J. Snodgrass, Jr.: "Comparison of Physical Properties When the Same Hardness is Obtained by Various Temperature-Time Tempering Cycles". Rock Island Arsenal Laboratory Report No. 44-5226, 1945.

**J. H. Hollomon: "Temper Brittleness. A Critical Survey and Interpretation", Watertown Arsenal Laboratory Report No. 630/11, 1945.

***J. H. Hollomon and L. D. Jaffe: "The Metallurgical Design of Steels for Optimum Mechanical Properties". Watertown Arsenal Report No. 320/28, 1945.

TABLE I

Tensile Test Results on SAE 1095

| Spec. No. | Tempering Time | Tempering Temp. | Rockwell "C" | Yield Strength P.S.I. .1% Set | Yield Strength P.S.I. 1% Set | Tensile Strength P.S.I. | Strain-Hard. Modulus P.S.I. | Fracture Stress P.S.I. | Elong. % | Red. of Area % | Fracture |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 19 | 5.3 min. | 548° C. | 39½ | 141,000 | — | 183,800 | — | — | 8 | 28.8 | Cup-cone |
| 20 | 5.3 min. | 548 | 39½ | 135,500 | 154,500 | 178,400 | 145,000 | 225,700 | – | 25.8 | — |
| 37 | 52.8 " | 482 | 41 | 152,000 | — | 192,000 | — | — | 8 | 24.7 | Cup-cone |
| 38 | 52.8 " | 482 | 41 | 142,000 | 170,000 | 186,400 | 170,000 | 233,900 | – | 23.4 | — |
| 25 | 17.6 hrs. | 415 | 41½ | 152,000 | — | 193,600 | — | — | 4 | 8.0 | * |
| 26 | 17.6 " | 415 | 41½ | 153,000 | — | 195,800 | — | — | 5 | 12.6 | * |
| 27 | 17.6 " | 415 | 41½ | 156,500 | 180,000 | 191,600 | ? | 208,800 | – | 8.2 | — |
| 40 | 5.3 min. | 652 | 29½ | 104,000 | — | 138,800 | — | — | 13 | 37.2 | Cup-cone |
| 42 | 5.3 min. | 652 | 29½ | 105,000 | 115,000 | 133,400 | 115,000 | 184,900 | – | 34.1 | — |
| 31 | 52.8 " | 580 | 30 | 108,000 | — | 143,000 | — | — | 13 | 38.6 | Cup-cone |
| 32 | 52.8 " | 580 | 30 | 105,500 | 113,800 | 135,500 | ? | 157,000 | – | 15.9 | — |
| 34 | 17.6 hrs. | 505 | 29½ | 105,000 | — | 139,000 | — | — | 14 | 39.8 | Cup-cone |
| 35 | 17.6 hrs. | 505 | 29½ | 105,500 | 113,500 | 131,400 | 111,000 | 188,500 | – | 37.9 | — |

*Irreg., cold-shut, crystalline.

## TABLE II

### Tensile Test Results on SAE 4140

| Spec. No. | Tempering Time | Tempering Temp. | Yield Strength P.S.I. .01% Set | Yield Strength P.S.I. .1% Set | Tensile Strength P.S.I. | Elong. % | Red. of Area % |
|---|---|---|---|---|---|---|---|
| 46 | 15 min. | 704° C. | 108,800 | 106,900 | 123,000 | 22.9 | 68.3 |
| 43 | 1 hr. | 675 | 110,600 | 107,500 | 124,000 | 22.9 | 69.2 |
| 40 | 16 hrs. | 618 | 111,200 | 107,500 | 123,000 | 22.1 | 68.3 |

## TABLE III

### V-Notch Charpy Impact Results on SAE 4140

| Spec. No. | Tempering Time | Tempering Temp. | Rockwell "C" | Energy Ft.-Lbs. | Remarks |
|---|---|---|---|---|---|
| | | | **Testing Temperature +20° C.** | | |
| 19 | 15 min. | 704° C. | 23 , 22½, 21½ | 111.7 | |
| 20 | 15 " | 704 | 23 , 22½, 21½ | 116.7 | Cracked |
| 25 | 15 " | 704 | - - - | 121.6 | |
| 27 | 1 hr. | 675 | 23½, 22½, 21½ | 116.2 | |
| 28 | 1 " | 675 | 24 , 23 , 22½ | 106.7 | |
| 1 | 16 hrs. | 618 | - - - | 101.6 | Cracked |
| 2 | 16 " | 618 | 22½, 22½, 21½ | 107.7 | |
| 6 | 16 " | 618 | - - - | 100.5 | |
| | | | **Testing Temperature -80° C.** | | |
| 21 | 15 min. | 704 | 23 , 22½, 21½ | 94.4 | |
| 22 | 15 " | 704 | 23½, 22½, 21½ | 98.5 | |
| 29 | 1 hr. | 675 | 23½, 23 , 20 | 93.4 | |
| 30 | 1 " | 675 | 23 , 22½, 21½ | 85.7 | |
| 3 | 16 hrs. | 618 | 21½, 22½, 21½ | 87.2 | |
| 4 | 16 " | 618 | 22½, 21½, 21½ | 92.9 | |
| | | | **Testing Temperature -195° C.** | | |
| 23 | 15 min. | 704 | - - - | 9.2 | Cracked |
| 24 | 15 " | 704 | - - - | 8.9 | |
| 26 | 15 " | 704 | - - - | 6.6 | |
| 31 | 1 hr. | 675 | - - - | 6.9 | |
| 32 | 1 " | 675 | - - - | 8.0 | Off-center impact |
| 33 | 1 " | 675 | - - - | 6.6 | |
| 5 | 16 hrs. | 618 | - - - | 6.6 | |
| 35 | 16 " | 618 | - - - | 6.4 | |

**Note:** All fractures fibrous.