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HEAT TREATMENT OF SAE 52100 STEEL

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1. INTRODUCTION

SAE 52100, a bearing steel, is capable of attaining a high hardness of Rockwell C60 and has excellent wear resistance at this hardness. This steel is used in applications where it must withstand wear, brinelling, and high tensile loads. When heat treated for bearing applications, 52100 steel is quenched with some undissolved pro-eutectoid carbides in the austenite. The resulting duplex structure is optimum for bearing applications because the hard carbides support the load while the softer matrix is depressed for good retention of the lubricant. Theory predicts that improved ductility and impact strength at high hardness can be obtained with a homogeneous, single-phase, tempered martensitic structure. This program was undertaken to develop a heat treatment which would provide the desired microstructure in 52100 steel.

2. CONCLUSIONS

2.1 The best combination of tensile properties (310 ksi ultimate strength and 2 per cent elongation) was obtained with the following heat treatment:

Austenitize at 1800 F for 1 hour per inch of thickness,
Quench into molten salt at 475 F and hold for 24 hours minimum,
Air cool to room temperature
Subzero cool at -100 F for 1 hour,
Warm to room temperature,
Heat to 400 F for 1 hour, and
Air cool to room temperature.

2.2 The tensile properties obtained showed more variation among specimens than was desired, and further evaluation should be performed before production use of this austempering heat treatment.

3. PROCEDURE AND RESULTS

3.1 Material

A 7/8 inch diameter bar of SAE 52100 steel in the spheroidize-annealed condition was purchased from a local warehouse. The certified chemical composition of the material reported by the vendor was:

Carbon	1.02	Silicon	0.25
Manganese	0.37	Chromium	1.36
Phosphorus	0.013	Nickel	0.13
Sulfur	0.014	Molybdenum	0.02

3.2 Heat Treatment and Testing

The first phase of the program was to determine the austenitizing temperature required to dissolve the pro-eutectoid carbides in austenite. Slugs of 52100 steel 1 inch long and 7/8 inch in diameter were austenitized for 1 hour at the following temperatures, then quenched in oil: 1525 F, 1600 F, 1700 F, 1750 F, 1800 F, 2000 F, and 2200 F. From the metallographic examination of each specimen, it was determined that the pro-eutectoid carbides were completely dissolved by austenitizing at 1800 F. Figures 1A through 1F show the microstructures of as-received material and of representative austenitized specimens.

The second phase of the program involved finding the modified austenitizing treatment that provided the best balance of strength and ductility. In addition, the properties obtained from austempering treatments were evaluated and compared to those obtained from the standard and modified quench and temper treatments. The austempering treatments used were approximated from TTT curves given in Reference 1. Tensile specimens of the configuration shown in Figure 2 were heat treated as noted in Table I and tested at room temperature in accordance with the procedure of Federal Test Method Standard No. 151a, Method 211.1. The results of these tests and of hardness determinations are given in Table I.

4. DISCUSSION

4.1 Conventional Heat Treatment

When heat treated conventionally (Table I, Specimens A1 through A5), 52100 steel specimens failed in a completely brittle manner with zero elongation. Only one of five tensile specimens elongated enough so that the 0.2 per cent offset yield strength could be obtained. The ultimate strength varied from 208.6 ksi to 311.2 ksi. The low strength of some specimens at high hardness can probably be attributed to the completely brittle behavior of the material, which prevents it from deforming around any microstructural discontinuity and thus increases the effect of the imperfection. The variation in strength may be due to variation in the amount and location of such discontinuities.

4.2 Modified Quench and Temper

Specimen B8 had the best balance of properties (8 per cent elongation but only 261 ksi ultimate strength) obtainable from a modified austenitizing treatment, in this case austenitizing at 1800 F, oil quenching, tempering at 400 F, subzero cooling, and tempering at 800 F. Austenitizing at 1525 F, quenching, tempering at 800 F, subzero cooling, and tempering at 800 F gave 7 per cent elongation and 236 ksi ultimate strength. Figure 3 shows the variation of strength and ductility with the temperature of the tempering treatment following subzero cooling. All specimens tempered below 750 F failed in a completely brittle manner. This tempering brittleness, a phenomenon encountered in some low alloy steels when tempering temperatures are between 500 F and 700 F, is not fully understood but is thought to be due to a precipitation of carbides from the martensite into the grain boundaries. The low ductility obtained with a 900 F tempering temperature (specimen B5) cannot be explained. Specimen B6 failed with zero elongation because of microcracks. These microcracks were probably formed during subzero cooling following the quench, which indicates that a stress-relief tempering (omitted in this case) is required between quenching and subzero cooling.

The treatment given to specimen B8 was chosen as the best quench and temper treatment. Although ductility (8 per cent elongation) can be achieved with this treatment, the strength and hardness are reduced to an extent which makes material so treated unsatisfactory for ultra-high-strength applications.

4.3 Austempering Treatments

Austempering is a heat treating process involving quenching after austenitizing to a temperature above the point where martensitic formation begins and below the range where high temperature transformation products are formed. The quenched material is held at a constant temperature until transformation of austenite to lower bainite is complete, and then cooled to room temperature. Following austempering, the test specimens were subzero cooled to transform any austenite remaining, and then tempered. The austempering treatment lowers the amount of distortion and residual stress and gives a tougher structure at high hardness with high carbon content than that obtained by quenching and tempering.

The lack of success in austempering from 1550 F was probably due to insufficient hardenability of the material when austenitized at this temperature. The lack of hardenability may have caused the formation of some upper bainite, a mixture of carbide and ferrite, during the rapid cooling to the austempering temperature. Upper bainite has low ductility and poor impact strength, and must be avoided to produce optimum strength with ductility. Austenitizing at 1800 F increased the hardenability of 52100 steel, but also increased the required holding time to complete the isothermal transformation to lower bainite. A minimum of 24 hours holding time was found to be necessary. Longer times would probably improve the reliability of the treatment, but the cost might be prohibitive.

Although the austempered specimens did have some ductility, they were extremely notch-sensitive. Specimens D4 and D6 broke in the fixture at a change of section; it is possible that tool marks or small imperfections initiated these failures through stress concentration. Threaded tensile specimens were prepared and heat treated, but tensile results could not be obtained because the specimens broke in the threads during test.

Austempering at 475 F for 24 hours minimum, following an 1800 F austenitizing treatment, gave the best combination of properties: 310 ksi ultimate strength and 2 per cent elongation. Although austempering from 1800 F improved the strength 50 ksi over that resulting from the conventional heat treatment, austempering was not considered completely satisfactory because of the large variation in properties obtained.

Further evaluation of heat treatments for 52100 steel was not pursued because it was felt that it would be more advantageous to investigate other materials for ultra-high-strength applications.

5. REFERENCE

1. Atlas of Isothermal Transformation Diagrams. United States Steel Corporation Research Laboratory, 2nd Edition, 1951.

TABLE I. HEAT TREATMENTS AND TEST RESULTS

Spec. No.	Heat Treatment					Tensile Properties			
	Austenitize F ± 5	Quench	Temper F ± 5	Subzero Treat F ± 5	Temper F ± 5	Fty 0.2% Offset ksi	Ftu ksi	Elong in 1 in. %	Hardness Rc
A1	1525	Oil	400	-	400	306.2	311.2	0	60.0
A2	1525	Oil	400	-	400	-	208.6	0	59.5
A3	1525	Oil	400	-	400	-	230.2	0	59.5
A4	1525	Oil	400	-	400	-	236.7	0	60.0
A5	1525	Oil	400	-	400	-	267.6	0	59.5
B1	1800	Oil	400	-100	400	-	131.2	0	61.5
B2	1800	Oil	400	-100	400	-	131.5	0	61.0
B3	1800	Oil	400	-100	600	-	121.3	0	58.0
B4	1800	Oil	400	-100	700	-	186.2	0	56.0
B5	1800	Oil	400	-100	900	194.5	223.4	3.0	50.0
B6	1800	Oil	-	-100	750, twice	230.6	230.6	0	54.0
B7	1800	Oil	400	-100	750	238.6	249.8	1.5	52.5
B8	1800	Oil	400	-100	800	223.4	261.8	8.0	52.5
B9	1800	Oil	400	-100	850	211.6	245.4	8.5	50.0
B10	1800	Oil	400	-100	775	221.6	262.1	6.0	51.0
B11	1800	Oil	800	-100	800	220.2	259.9	5.0	51.0
B12	1525	Oil	800	-100	800	217.2	236.1	7.0	48.5

TABLE I. HEAT TREATMENTS AND TEST RESULTS (Continued)

Spec. No.	Heat Treatment						Tensile Properties			
	Austeni-tize F ± 5	Quench F ± 5	Quench hr	Temper F ± 5	Subzero Treat F ± 5	Temper F ± 5	Fty 0.2% Offset ksi	Ftu ksi	Elong in 1 in. %	Hard-ness Rc
D1	1550	500	1	-	-	-	-	281.1	0	59.5
D2	1550	500	1	400	-	-	-	293.6	0	58.5
D3	1800	475	168	-	-	-	274.1	329.7	3.4	58.5
D4	1800	475	168	-	-100	400	277.2	329.0	2.5	58.5
D5	1800	475	72	-	-100	400	266.0	*284.5	0	57.0
D6	1800	475	96	-	-100	400	268.8	*329.6	0	57.0
D7	1800	475	24	-	-100	400	257.6	322.3	3.0	57.5
D8	1800	475	48	-	-100	400	257.7	316.4	3.5	57.5
D9	1800	475	36	-	-100	400	253.3	316.4	3.5	57.0
D10	1800	475	12	-	-100	400	-	56.1	0	60.0
D11	1800	475	20	-	-100	400	-	194.3	0	59.0
D12	1800	475	24	-	-100	400	263.3	317.5	3.0	58.0
D13	1800	475	24	-	-100	400	251.1	304.8	2.0	58.0
D14	1800	475	24	-	-100	400	241.8	281.1	1.5	58.5

* Broke in fixture at change of section

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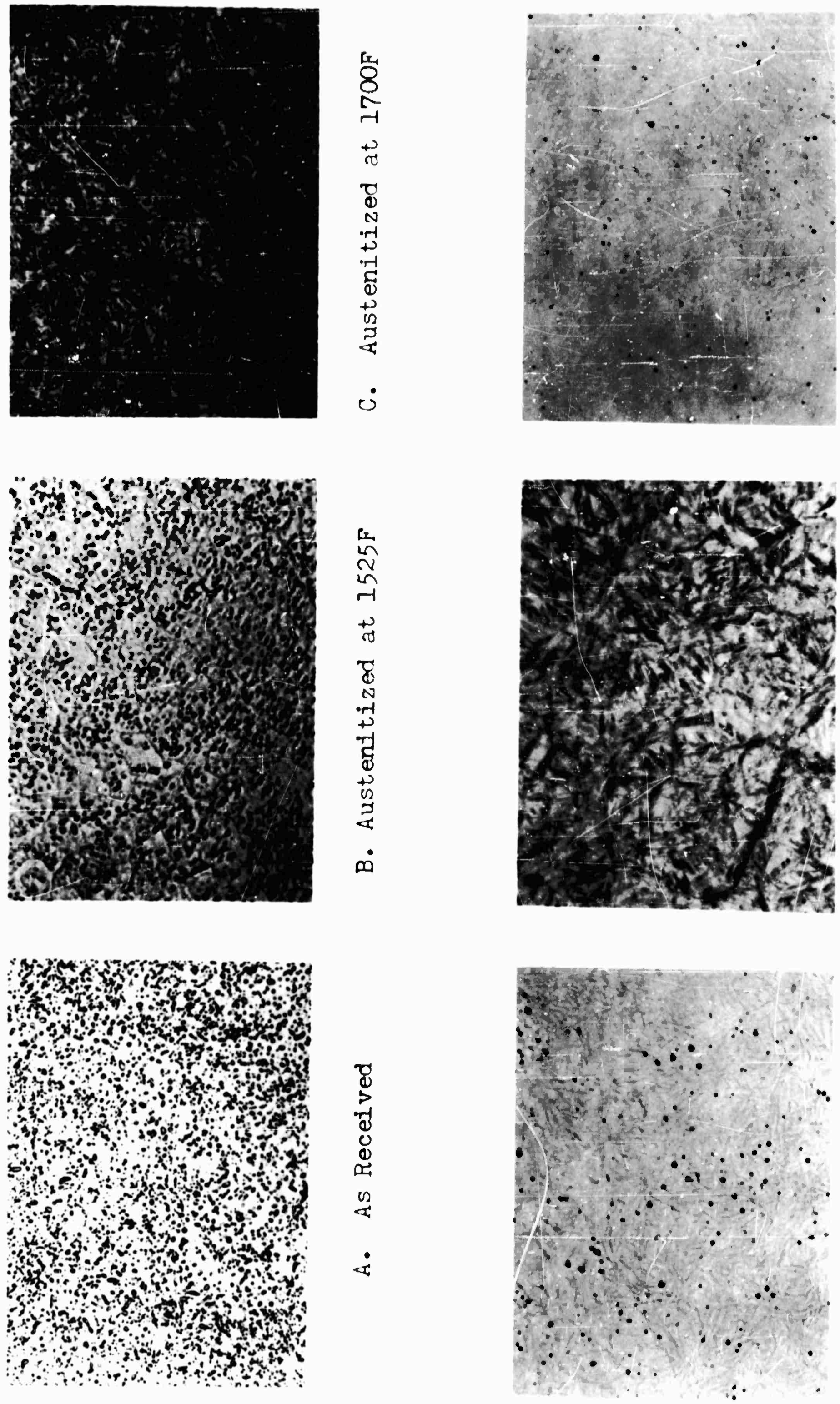

Figure 1. Microstructures of As-received Material and Austenitized Specimens
(Murakami's Etchant; 750X)

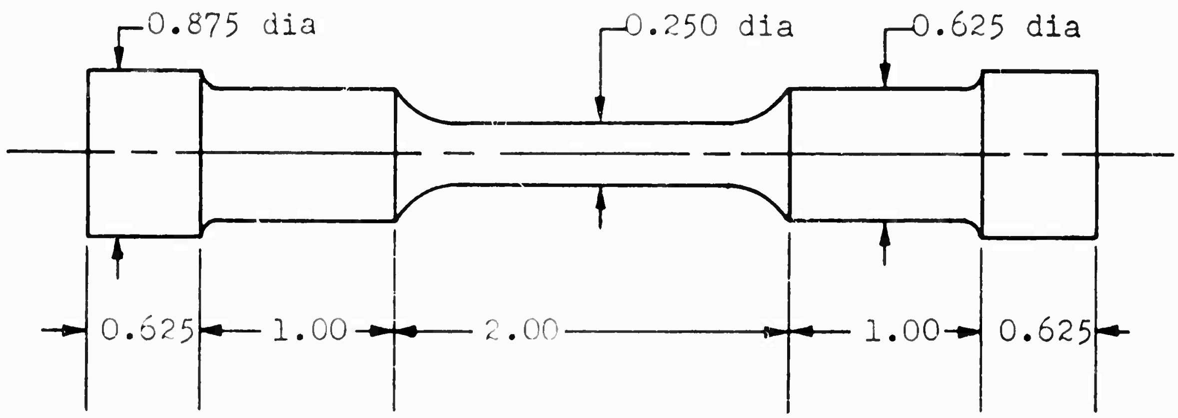

Figure 2. Tensile Test Specimen Configuration

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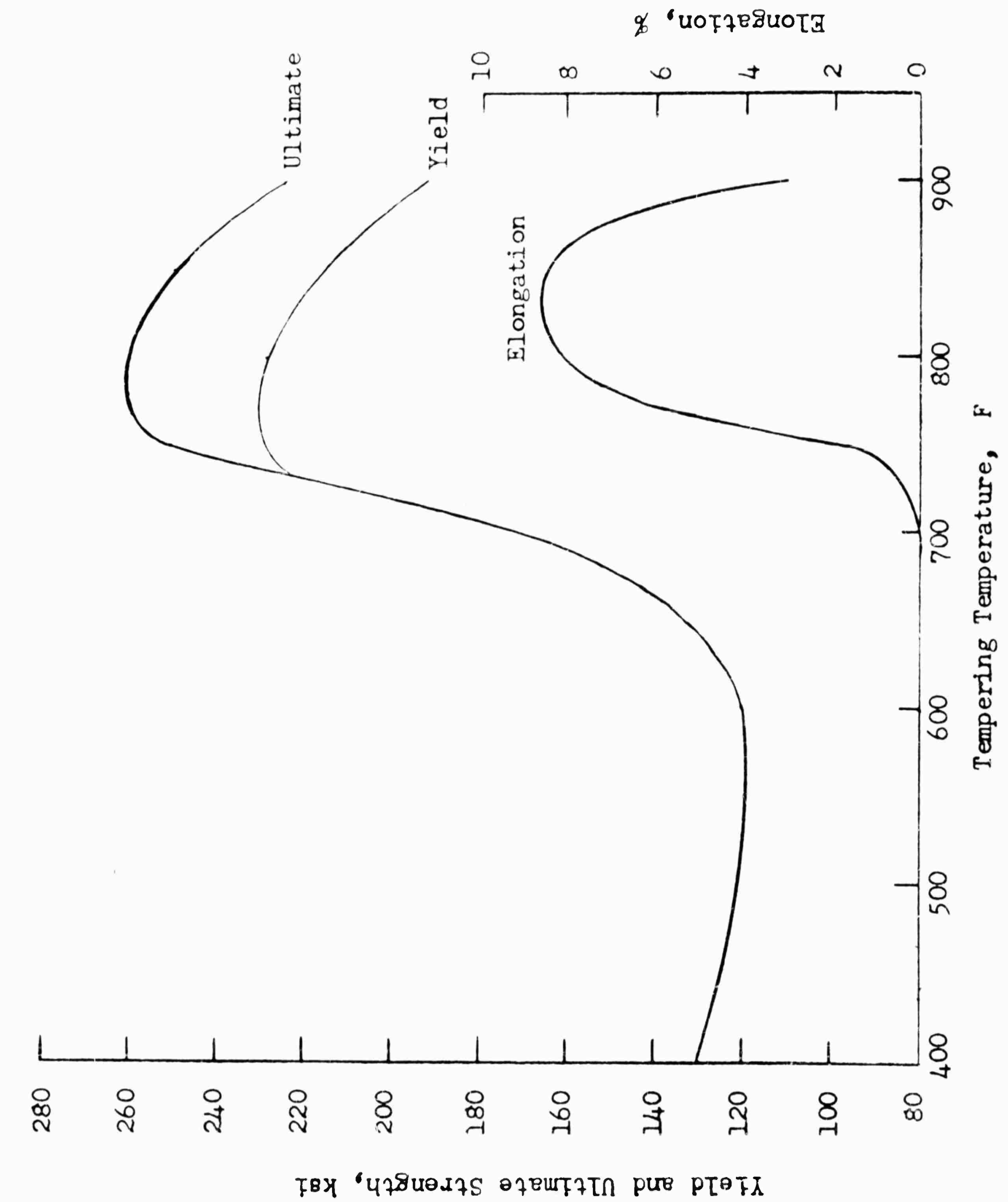

Figure 3. Variation of Tensile Properties With Tempering Temperature