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3,330,705
METHOD TO IMPROVE IMPACT PROPERTIES
OF STEELS
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19 Claims. (Cl. 148—12)

This is a continuation application of application Ser. No. 375,302, filed June 15, 1964, now abandoned, which

charpy V-notch type; and the steel was semi-killed and has a base composition within the following ranges:

Element:	Wt. percent
C	0.12–0.24.
Mn	0.47–0.54.
P	0.008–0.012.
S	0.027–0.039.
Si	0–0.09
Fe	Balance, essentially.

In a mild carbon steel containing small additions of columbium in conventional amounts (e.g., 0.0010–.030 wt. percent and preferably 0.020–0.025 wt. percent), the strength of the steel increases with an increase in the soaking temperature, as indicated in Table I hereinbelow.

TABLE I

Soaking Temperature (° F.)	Yield Point (p.s.i.)	Ultimate Tensile Strength (p.s.i.)	Hardness Rockwell "B"	Elongation in 2"	15 ft.-lb. Transition Temperature, ° F.
2,400					+120
2,200	50,000	67,000	77	33	+90
2,000	48,000	65,000	75	35	+30
1,900	45,000	61,000	71	39	-10
1,800	45,000	60,000		40	-30
1,700	45,000	60,000	69	40	-30

was a continuation-in-part of application Ser. No. 131,096, filed Aug. 14, 1961, now abandoned.

The present invention relates generally to a method for improving the impact properties of hypoeutectoid steels, especially columbium-containing mild carbon steels, and more particularly to a method for improving the impact properties of these steels while retaining high strength.

Essentially, the invention relates to a method including the steps of soaking or heating a mild carbon hypoeutectoid steel (e.g., 0.12–0.40 wt. percent carbon, for example) at a temperature which is in the austenitic range for the steel being heated, then cooling to a temperature at which the steel's microstructure contains both ferrite and austenite, deforming the steel at this lower temperature after the cooling step, and then air cooling the steel to room temperature without further deformation or heat treating. Generally, this treatment improves the impact properties of the steel while retaining relatively high tensile strength, yield strength and hardness.

Optimum values of high strength and good impact properties can be obtained by utilizing conditions to be subsequently described.

In the following tabulations, the steel test specimen for determining impact properties was of the conventional

The specimen for Table I contained 0.025 wt. percent columbium, and was heated at the soaking temperature for about one-half hour. All the soaking temperatures are in the austenitic range, and recrystallization to provide grains of austenite occurs during this soaking.

It will be noted from Table I that when the soaking temperature was reduced from 2000° F. to 1900° F., there was a greater increase in ductility and resistance to impact than for any other reduction of 100° F. in temperature, and the corresponding decrease in strength and hardness was relatively insignificant in comparison to the increase in impact properties. Therefore, between 1900° F. and 2000° F. there is a soaking temperature which is the optimum for the steel being tested, from the standpoint of combined strength and resistance to impact; and examination of steel microstructures indicates that this optimum soaking temperature corresponds to the grain coarsening temperature for the steel. As used herein, the term "grain coarsening temperature" is the highest temperature before the appearance of coarse grains, e.g., the temperature at which the ASTM grain size after soaking for one half-hour is 5 or less.

Increasing the columbium content increases the grain coarsening temperature for a given steel, as indicated by Table II.

TABLE II.—THE EFFECT OF COLUMBIUM CONTENT ON THE GRAIN COARSENING TEMPERATURE OF COLUMBIUM TREATED STEELS

Columbium Content, Percent	ASTM grain size after annealing ½ hr. at the following temperatures—								Highest Temperature Before Grain Coarsening, ° F.
	1,700° F.	1,800° F.	1,900° F.	2,000° F.	2,100° F.	2,200° F.	2,300° F.	2,400° F.	
0.000	4-8	4-8	4-6	3-4	2-4	1-3	1-3	1	
0.001	5-7	1-3	1-3	1-2	1-2	1-2			
0.005	7-9	1-8	1-5	1-3	1-2	1-2			
0.013	6-9	7	1-3	1-3	1-3	1-2			1,700
0.025		10-11	9-10	3-5	3-5	2-4	2-4	1-2	1,800 1,900

Thus, to obtain a combination of high strength and good impact properties, it is advantageous to heat the steel at a temperature which is in the all-austenitic region for the steel, and at as high a temperature as is possible without exceeding the grain coarsening temperature for the steel being heated.

Table III, hereinbelow, shows the correlation between grain size and resistance to impact.

TABLE III.—THE TRANSITION TEMPERATURE AND FERRITE GRAIN SIZE OF COLUMBIUM TREATED STEEL AS AFFECTED BY VARIOUS SOAKING TEMPERATURES

Soaking Temperature, ° F. ¹	ASTM, Grain Size	Dominant ASTM, Grain Size	15 ft.-lb. Ductility Transition Temperature, ° F.
2,400 ²	-----	-----	120
2,200 ²	-----	-----	87
2,000 ²	6, 7, 8	7	58
1,950 ³	7, 8, 9, 10	8	30
1,900 ³	9, 10, 11	10	-10
1,800 ³	10, 11	10	-20
1,740 ³	9, 10, 11	10	-30
1,720 ³	10, 11, 12	11	-50
1,620 ³	10, 11, 12	11	-50

¹ 30 minute soak at temperature followed by 20% reduction at 1,500° F

² .025% columbium.

³ .021% columbium.

It will be noted that for a columbium content between 0.021 and 0.025, the grain coarsening temperature is between 1900 and 2000° F. As the soaking temperature decreases substantially below the grain coarsening temperature, there is a small increase in ductility, but not nearly so great as the increase in ductility resulting from a temperature change from slightly over the grain coarsening temperature to slightly under the grain coarsening temperature. Furthermore, when the soaking temperature is one which is not fully austenitic for the steel in question (as would be the case if the steel were soaked at 1500° F.) the increase in impact properties does not occur. Thus, for the steel of the examples, about 1950° F. $\pm$ 50° F. is the optimum soaking temperature.

Another factor to be considered in obtaining the optimum combination of high strength and good impact resistance is the rolling temperature. It has been determined that for mild carbon steels including amounts of columbium in accordance with the present invention, the optimum combination of strength and impact resistance is obtained by rolling at 1500° F., a temperature materially above the A_1 temperature for the steel. The effect of varying the rolling temperature above and below 1500° F. is shown in Table IV hereinbelow.

TABLE IV.—THE TRANSITION TEMPERATURE AND FERRITE GRAIN SIZE OF COLUMBIUM TREATED STEEL AS AFFECTED BY VARIOUS ROLLING TEMPERATURES

Rolling Temperature, ° F. ¹	ASTM, Grain Size	Dominant ASTM, Grain Size	15 ft.-lb. Ductility Transition Temperature, ° F.
1,900 ²	5, 6, 7, 8	7	20
1,800 ²	6, 7, 8	7	10
1,700 ²	7, 8	7	27
1,600 ²	7, 8	8	15
1,500 ²	9, 10, 11	10	-10
1,400 ³	6, 7, 8	6	35
1,300 ³	5, 6, 7	6	90
1,200 ³	5, 6, 7	7	85
1,100 ³	5, 6, 7	6	130

¹ 30 minute soak at 1,900° F. followed by 20% reduction at indicated temperatures.

² .025% columbium.

³ .021% columbium.

For the steel under consideration in Table IV, 1500° F. is in a two-phase region (austenite and ferrite); and under the specified conditions of temperature and deformation, grain recrystallization will occur without substantial grain growth so that a relatively fine ferrite grain size is obtained.

With respect to the treatment heretofore described for mild carbon, columbium-containing steels, the soaking temperature was about one-half hour, but may vary depending upon the thickness and shape of the steel being soaked. The criterion for determining the length of the soaking period is that the period be long enough for the desired amount of grain recrystallization to occur. In other words, the soaking step should be carried out under time and temperature conditions which cause recrystallization, but which do not permit substantial grain growth or coarsening.

With respect to the conditions for the rolling step, sufficient deformation should be performed to induce recrystallization of fine grains at the rolling temperature (see Table IV). For a steel having a composition as set forth in the examples, a maximum amount of deformation is about 20%, and the rolling temperature is about 1500° F. This temperature corresponds to the minimum temperature at which recrystallization of the ferrite grains can be obtained without substantial grain growth. Above 1500° F., ferritic grain growth would occur. Below 1500° F., substantial recrystallization would not occur.

As previously indicated, the deformation or rolling step is performed after a cooling step in which the steel is cooled until its microstructure contains ferrite and austenite; and the temperature to which the steel is cooled is controlled so that recrystallization of the ferrite grains occurs throughout the deforming step. Thus, the microstructure contains ferrite and austenite at both the beginning and the end of the deformation step.

A cooling step follows the deformation step; and since the deformation step is performed at a temperature within the austenite plus ferrite region for the steel, the cooling step is initiated at a temperature within this region.

The final microstructure resulting from treating columbium-containing steel in accordance with the method of the present invention is one having a fine ferrite grain size.

It should be emphasized that subjecting the steel to further deformation and/or heat treatment, following the treatment described above, destroys the desirable properties resulting from said treatment, and should therefore be avoided.

Although the invention has heretofore been discussed primarily with respect to mild carbon steels containing columbium, it is also applicable to mild carbon steels without columbium. For example, when a mild carbon steel having the aforementioned base composition, but containing no columbium, is heated at a temperature in the austenitic region for the steel, but below the grain coarsening temperature for the steel, is then cooled to a temperature which is in a two-phase (ferrite and austenite) region for the steel and which is materially above the A_1 temperature for the steel and the steel is partially deformed at the lower temperature, and is then air cooled to room temperature, without further deformation or heat treating, an optimum combination of strength and impact resistance will be obtained for the steel.

Table V shows the effect of soaking temperatures on the impact resistance of a mild carbon steel without columbium.

TABLE V

Soaking temperature, ° F.:	15 ft.-lb. ductility transition temperature, ° F.
1900	15
1800	13
1700	15
1620	-58

With reference to Table V, the grain coarsening temperature for the steel in question is between 1620° F. and 1700° F. For this same steel, the optimum rolling temperature would be about 1500° F., this being the lowest temperature at which recrystallization of ferrite grains can be obtained without substantial grain growth.

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Essentially, the method for improving the impact properties of steel, herein described, relates to hypoeutectoid steels, and especially to mild carbon steels having a carbon content between 0.12 and 0.40 wt. percent. The method is particularly applicable to mild carbon steels containing small additions of columbium in conventional amounts, e.g., 0.0010–0.030 wt. percent, but is not limited thereto.

The foregoing detailed description has been given for clearness of understanding only, and no unnecessary limitations should be understood therefrom, as modifications will be obvious to those skilled in the art.

What is claimed is:

1. A method for treating a hypoeutectoid steel, said method comprising the steps of:
 - soaking said steel at a temperature, in the austenitic region but below the grain-coarsening temperature for said steel, and for a time which produces grain recrystallization without substantial grain growth for said steel;
 - cooling said steel to a lower temperature, in the ferrite plus austenite region for said steel and at which the microstructure of the steel contains both ferrite and austenite;
 - said lower temperature being materially above the A_1 temperature for said steel;
 - deforming said steel at said lower temperature after said cooling step;
 - said deforming step being initiated when the microstructure of the steel contains both ferrite and austenite;
 - controlling said lower temperature and said deformation to produce fine-grain ferrite recrystallization without substantial ferritic grain growth as a result of said deformation at said lower temperature; and then cooling said steel to room temperature without further deforming or heat-treating;
 - said steel being at a temperature in the ferrite plus austenite region for the steel when said last-recited cooling step is initiated.
2. A method as recited in claim 1 wherein said soaking is performed at substantially the maximum temperature which does not exceed the grain-coarsening temperature for said steel.
3. A method as recited in claim 2 wherein:
 - said steel is in the austenitic region at a temperature above 1500° F. and is in the ferrite plus austenite region at 1500° F.;
 - and said steel is deformed at 1500° F.
4. A method as recited in claim 3 wherein said steel is deformed up to 20% at 1500° F.
5. A method as recited in claim 4 wherein said steel contains 0.12–0.40 wt. percent carbon.
6. A method as recited in claim 4 wherein said steel is heated for about one-half hour at said soaking temperature.
7. A method as recited in claim 2 wherein said steel is deformed up to 20% at said lower temperature.
8. A method as recited in claim 2 wherein said steel is heated for about one-half hour at said soaking temperature.
9. A method as recited in claim 2 wherein said steel is air-cooled following said deformation.
10. A method for treating a columbium-containing hypoeutectoid steel, said method comprising the steps of:
 - soaking said steel at a temperature, in the austenitic region but below the grain-coarsening temperature

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- for said steel, and for a time which will produce grain recrystallization without substantial grain growth for said steel;
- cooling said steel to a lower temperature, in the ferrite plus austenite region for said steel and at which the microstructure of the steel contains both ferrite and austenite;
- said lower temperature being materially above the A_1 temperature for the steel;
- deforming said steel at said lower temperature after said cooling step;
- said deforming step being initiated when the microstructure of the steel contains both ferrite and austenite;
- controlling said lower temperature and said deformation to produce fine-grain ferritic recrystallization without substantial ferritic grain growth as a result of said deformation at said lower temperature; and then cooling said steel to room temperature without further deformation or heat-treating;
- said steel being at a temperature in the ferrite plus austenite region for the steel when said last-recited cooling step is initiated.
11. A method as recited in claim 10 wherein said soaking is performed at substantially the maximum temperature which does not exceed the grain-coarsening temperature for said steel.
12. A method as recited in claim 11 wherein:
 - said steel is semi-killed and contains up to 0.40 wt. percent carbon and 0.0010–0.030 wt. percent columbium.
13. A method as recited in claim 12 wherein:
 - said steel contains 0.020–0.025 wt. percent columbium;
 - said soaking is performed at 1900–2000° F.; and said deforming is performed at 1500° F.
14. A method as recited in claim 13 wherein said steel contains 0.12–0.24 wt. percent carbon.
15. A method as recited in claim 13 wherein said soaking is performed for about one-half hour.
16. A method as recited in claim 15 wherein said steel is deformed up to 20 percent.
17. A method as recited in claim 13 wherein said steel is deformed up to 20 percent.
18. A method as recited in claim 12 wherein:
 - said steel contains 0.12–0.24 wt. percent carbon and 0.020–0.025 wt. percent columbium;
 - said soaking is performed for about one-half hour; and said steel is deformed up to 20 percent.
19. A method as recited in claim 11 wherein said steel is air-cooled following said deformation.

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