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[54] **PROCESSING OF STEEL BARS AFTER HOT ROLLING**

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Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 768,163, Oct. 16, 1968, abandoned.

[52] **U.S. Cl.** ..... **148/12 C,** 148/156

[51] **Int. Cl.** **C21d 7/14**

[58] **Field of Search** 148/12, 156

[56] **References Cited**

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[57] **ABSTRACT**

Steel bars are rapidly cooled from hot rolling temperature to a temperature of about 1,500° F. and are then cooled at a much lower rate to a temperature below their lower transformation temperature to minimize their compressive flow strength and improve their cold-heading and forming properties.

3 Claims, No Drawings

PROCESSING OF STEEL BARS AFTER HOT ROLLING

This application is a continuation-in-part of our application Ser. No. 768,163, filed Oct. 16, 1968, and now abandoned.

This invention relates to the manufacture of hot-rolled steel bars. It is more particularly concerned with methods of processing such bars immediately after hot rolling to improve their cold-heading and forming properties.

The steel bars with which our invention is concerned are ordinary low to medium carbon steel bars intended for cold heading, forging or upsetting. The greater proportion of these is made from steels of about 0.20 percent to 0.45 percent carbon content. These steels are generally straight carbon steels, but may contain small amounts of alloys which affect hardenability. In small diameters such bars are generally coiled hot, but in larger sizes are processed as straight lengths or strand.

Historically, the cold-heading properties of steel bars have been optimized by giving them a spheroidizing anneal. This treatment, however, is time-consuming and expensive. It is the principal object of our invention to avoid this treatment while obtaining the properties which it imparts. It is another object to provide a process for treating bars directly from the hot rolling mill which optimizes their cold-heading properties. It is another object to provide such a process adapted for bars which are coiled hot. It is another object to provide such a process for bars which are processed as straight lengths or strand.

The two properties of a steel that characterize its behavior during cold forming are its compressive flow stress (a measure of its strength) and its fracture strain at failure (a measure of its ductility). Low and medium carbon steels, free of excessive inclusions and surface defects, can be upset at least 70 percent without evidence of external cracking. Since cold-forming equipment is, in general, not designed to exceed these strains during each cold-forming operation, the strain capacity of these steels is usually not a problem. The compressive strength, however, is important since this reflects how large a load the steel imparts to the die and punch during the cold-forming operation.

We have found that the compressive flow stress at large strains depends on the following factors in accordance with the following relationship:

Flow Stress = $95 + .39(d^{-1/2}) + 0.58$ (percent Pearlite) + 25.8 (percent Si) (1000 psi) (67 percent Upset)

where d in the grain size term ($d^{-1/2}$) is the mean linear intercept of ferrite in inches, and percent Si is the silicon content of the steel.

This equation shows that a decrease in the gran size and decrease in the pearlite and silicon contents of a carbon steel will improve its cold-forming behavior. There are two methods to accomplish this in practice: (1) to change the chemistry of the steel, or (2) to alter the structure of the steel through processing changes. If it is not possible to lower the carbon, manganese, or silicon contents of a grade, for example, where the contents of these elements are determined by hardenability requirements, improvements in the cold-forming behavior of hot-rolled steels can only be accomplished either by lowering the pearlite content or by decreasing the ferrite grain size through control of processing conditions.

During hot rolling on a bar mill where the deformations per pass are fixed, the austenitic grain size after complete recrystallization decreases with lower hot rolling and/or finishing temperature. We have found, however, that this recrystallization takes place so rapidly that it is not possible to quench deformed austenite to a lower temperature and allow it to recrystallize to a smaller grain size. For the same reason we have found that the hot deformed structure of austenite in plain carbon steels cannot be utilized to refine the ferritic grain structure by direct transformation to ferrite from recrystallized austenite.

Table I summarizes the temperature dependence in 1030 steel of austenitic grain size (ASTM No.) immediately after complete recrystallization at the times noted, and after one hour, at the hot rolling temperatures noted:

TABLE I

FINISHING TEMPERATURE	TIME (SEC.) FOR COMPLETE RECRYSTALLIZATION	AUSTENITIC GRAIN SIZE (ASTM NO.) AFTER RECRYSTALLIZATION	AFTER ONE HOUR
2000° F.	0.2	2.3	0.5
1900° F.	0.5	3.5	1.0
1800° F.	0.4	4.5	2.5
1700° F.	0.6	5.4	4.0
1600° F.	1.2	6.3	5.4
1500° F.	2.0	7.0	6.5

It is seen that considerable grain growth occurs at high temperatures if a steel is held at these temperatures after rolling; however, very little grain growth occurs if the steel is cooled to 1,500° F. The austenitic grain sizes observed after 1 hour are comparable to those which would be obtained if a carbon steel without any grain refining elements were reheated to these temperatures for 1 hour.

We have found that desirable cold-heading properties are imparted to steel bars by cooling them from hot rolling temperature in two steps or stages, the first comprising rapid cooling to a temperature of about 1,500° F. and the second comprising slow cooling from that temperature through the transformation range of the steel.

A hot bar cools by heat loss from its surface. While this is going on the temperature of the center of the bar is always higher than the temperature of the bar surface. In a large bar being rapidly cooled this temperature differential is considerable. To insure minimum grain growth it is desirable to cool the bar coming from the mill at 1,800° F. to 2,000° F. to a temperature which is above its lower transformation temperature as rapidly as possible. Too rapid a quench, however, will transform the surface of the bar into bainite or even

martensite, both of which structures are undesirable in cold-heading steels, and we adjust the cooling of the bar to avoid this condition. There is no difficulty in this respect if the surface of the bar is not allowed to fall below about 1,200° F. We have found that a ⅝ inch diameter bar allowed to cool in still air at room temperature from a mill finishing temperature in the range above mentioned to a temperature of about 1,500° F. exhibits tolerable grain growth. We adjust the rapid cooling of our bars to a rate not less than that of the ⅝ inch diameter bar above mentioned. The measured rate of cooling at the center of such a bar is about 300° F. per minute. Our rapid cooling step is not limited to air cooling, either in still air or by forced draft. We also utilize water cooling, especially for bars of larger diameter, but adjust it to bring about cooling at the rates above set out.

The rapid cooling step of our process is carried out with the bar in strand form or in sheared lengths as it comes from the rolling mill. Bar rolling mills are conventionally provided with run-out tables or with cooling beds on which the hot bars are delivered. We provide these run-out or cooling beds with means for directing cooling water or air against the hot bars to cool them in the way we have described.

Bars that are coiled continue to cool in the coil but because of the mass of the coil such cooling continues slowly. We have found that the rate of that cooling and the temperature from which the cooling starts influence the structure and the properties of the bar quite significantly. Table II tabulates data illustrating the effect of coiling temperature and cooling rate on the structure, hardness, and compressive flow stress of a bar of 10B22 steel. This steel analyzed 0.24 percent carbon, 0.82 percent manganese, 0.19 percent silicon, 0.021 percent aluminum, 0.001 percent boron and the remainder iron.

scribed for coils, or alternatively, the bar either as strand or as successive sheared lengths is passed continuously through a gradient furnace or cooling chamber. This furnace or chamber is provided with heating means and/or heat insulation which are adjusted so that the bars enter at temperatures slightly below those they attain at the end of the fast cooling stage and as they move through cool at the rate and to the exit temperature which we describe.

The first cooling step of our process is therefore adapted to prevent austenite grain growth after hot rolling and the second cooling step is adapted to cause the austenite to transform to ferrite plus pearlite slowly enough to result in minimum pearlite content of the resulting microstructure. Those skilled in the metallurgical art know that for a given steel composition there is a theoretical minimum proportion of pearlite which can be obtained, the equilibrium pearlite content, which can be calculated from the iron-carbon phase diagram. The conditions of our process are selected so as to provide a pearlite content as near to this minimum as is commercially feasible for steels of cold-heading composition range. The embodiment of our process presently preferred by us comprises rapidly cooling the bar from conventional hot-rolling finishing temperatures, around 1,800° to 1,900° F., to a temperature not greater than about 1,500° F. and not lower than the transformation temperature of the steel, followed by slow cooling through the lower transformation temperature of the steel to a temperature of about 1,200° F. or lower.

The microstructure and properties listed in Table II of the bars coiled at 1,500° F. and cooled from that temperature at a rate of 50° F. per hour are very desirable in cold-heading steel. Bars coiled at 1,500° F. and cooled from that temperature at a rate of 500° F. per hour are only marginally worse, but those coiled at

TABLE II

COILING** TEMPERATURE (°F.)	COOLING RATE	% PEARLITE	GRAIN SIZE $D^{-1/2}(IN.^{-1/2})$	HARDNESS R_B	COMPRESSIVE FLOW STRESS (1000 PSI); ϵ = TRUE STRAIN ϵ=0.5	ϵ=0.2	ϵ=0.4	ϵ=0.6	ϵ=0.8	ϵ=1.0
1900	50°F/HR.	35	18	70	61	84	92	96	103	115
1700	50°F/HR.	33	30	70	63	85	93	97	104	116
1500	50°F/HR.	26	31	70	61	83	92	96	102	117
1900	500°F/HR.	31	30	73	66	87	96	100	105	116
1700	500°F/HR.	30	31	74	66	87	95	100	105	118
1500	500°F/HR.	27	32	72	64	86	97	100	107	121
1900	80°F/MIN.	32	35	81	71	93	101	106	112	126
1700	80°F/MIN.	28	38	81	72	94	102	106	113	128
1500	80°F/MIN.	30	38	81	72	94	103	108	116	134
AIR COOLED	6°F/SEC.	43	49	90	86	107	116	120	127	142

** The finishing temperature of all bars was 1900°F. For 1700°F. and 1500°F. coiling temperatures, bars were air cooled from 1900°F. to these temperatures at 6°F/SEC.

From Table II it may be seen that bars coiled at 1,500° F., the lowest temperature shown, and cooled in the coil at a rate of 50° F. per hour, the slowest rate shown, had the smallest grain size, the smallest amount of pearlite in their microstructure, the lowest hardness, and the lowest compressive flow stress at various values of strain.

The slow cooling step of our process is carried out in different ways, depending on the form in which the bar is delivered. As we have mentioned, small diameter bars are conventionally coiled. Such coils range from less than 1,000 to as much as 3,000 pounds in weight.

Bars in the form of strand or of sheared lengths are slow cooled by our process in the same way as is de-

1,500° F. and cooled at a rate of 80° F. per minute, or 4,800° F. per hour, are quite noticeably inferior. We prefer, therefore, to cool bars coiled at a temperature of 1,500° or thereabouts at a rate not greater than about 10° F. per minute. Large coils on the order of 3,000 pounds or greater will cool at this rate or slower in still air at room temperature because of their mass. Smaller coils cool at higher rates. For example, we have measured the cooling rate of a 1,450 pound coil of 17/32 inch diameter bar in the temperature range of 1,500° F. to 1,200° F. as 930° F. per hour. We retard the rate of cooling of small coils by placing them inside insulated boxes or covers until they have cooled to a safe temperature.

Cooling should proceed at the desired rate above mentioned until all the austenite in the steel is transformed into ferrite and pearlite. Those skilled in the metallurgical art known that this transformation takes place over a range of temperatures that varies with the carbon content of the steel and the speed of the cooling. For low and medium carbon steels with which this invention is concerned, and cooling rates not greater than about 10° F. per minute, a lower temperature for the slow cooling range of about 1200° F. is satisfactory. Below that temperature the steel may be cooled at any rate desired without affecting its cold heading properties.

We claim:

1. The method of processing steel bars of cold-heading grade immediately after hot rolling to produce optimum cold-heading properties, the hot-rolling finishing temperature being above 1,500°F., including a fast cooling step followed by a slow cooling step, the fast cooling step comprising cooling the hot bar to a temperature not greater than about 1,500° F. but above its lower transformation temperature at a cooling rate not less than about 300° F. per minute but not great enough to form bainite or martensite at the bar surface, and the slow cooling step comprising cooling the bar through its lower transformation temperature to a temperature of not more than about 1,200° F. at a cooling rate not greater than about 10° F. per minute.

2. The method of claim **1** in which the hot bar is coiled at the conclusion of the fast cooling step and the slow cooling step is carried out with the bar in coil form.

3. The method of claim **1** in which the slow cooling step is accomplished by passing the bar in strand form through a zone of temperature decreasing from a value above the lower transformation temperature at its entry end to a value below the lower transformation temperature at its exit end.

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