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METHOD OF PROCESSING STEEL

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This invention relates to a method of processing steel to produce a substantially non-aging ductile product. More particularly, the invention is directed to a treatment which produces a ductile steel having a fine-grained structure, i.e. a structure with a grain size not larger than ASTM No. 7, and which has a high yield strength.

Steel produced according to the invention possesses non-aging properties which permit long-term storage prior to usage without significant change in mechanical properties. The steel is a cold reduced product and possesses a uniformity of thickness significantly better than hot rolled material. The surface quality of the steel processed by my invention is very good and the surface is free of minute cracks or coil breaks such as are normally found in hot rolled material. This steel is particularly useful as bumper stock material for automobiles.

Steel is processed according to my invention by adding a nitrogen-bearing compound to a melt of aluminum-killed, low carbon steel which has a carbon content of at least about 0.08%. The nitrogen-bearing compound is added in an amount to provide a final nitrogen content in the steel of from 0.008 to 0.015% by weight, and the nitrogenized steel is then solidified. Nitrogen in the steel is substantially completely dissolved by maintaining the steel at nitrogen dissolution temperature, preferably about 2200° F. or higher. The steel is then hot rolled at a temperature above 1520° F. to achieve a partial reduction in thickness to the desired final gauge. After hot rolling, the steel is rapidly cooled to a temperature below 1100° F. to minimize precipitation of aluminum-nitride. The steel may be pickled if desired and is then cold reduced to finishing thickness less the reduction to be accomplished in final temper rolling. Following cold reduction, the steel is annealed for a time sufficient to obtain a recrystallized elongated grain structure wherein the grains are not larger than ASTM No. 7 and to precipitate aluminum-nitride around the grains. The precipitated aluminum-nitride forms an envelope surrounding the grains and restricts growth of the grains during annealing. After annealing, the steel is temper rolled to increase the yield strength and produce the desired final mechanical properties.

In the preferred practice of my process, a low carbon steel having 0.08-0.2% carbon, 0.6% manganese max. and 0.02% silicon max. is "killed" by adding aluminum to the steel melt while in the ladle. The term "killed" refers to deoxidation of the metal until gas evolution is completed and the melt is quiescent. Nitrogen is added to the steel for grain refinement and to improve the strength of the steel. It also has the effect of increasing the work hardening rate so that the desired strength level, e.g. at least 35,000 p.s.i. yield strength, can be achieved with a small final reduction on the cold rolling mill (i.e. a small extension during temper rolling). Nitrogen is preferably introduced to the steel by a nitrogen-bearing compound, such as calcium cyanamide, which is added to the steel in an amount sufficient to provide a final nitrogen content of between 0.008% to 0.015% by weight. The amount of nitrogen in the steel is important since if too little is present, there will be insufficient improvement in strength, and unduly large amounts of nitrogen will adversely affect the steel's ductility.

After nitrogenizing and solidification, the steel is subjected to a sufficient temperature to accomplish substan-

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tially complete dissolution of the nitrogen. Significant nitrogen dissolution can occur above about 1500° F., but higher temperatures, e.g. above about 2200° F., are preferred because the dissolution rate is greater and substantially complete dissolution can be accomplished in a shorter time. The steel is hot rolled to achieve a part of the total reduction in thickness required; however, hot rolling must be performed above about 1520° F. so that hot rolling can be completed without significant nitrogen precipitation. Following the final hot rolling, the steel must be rapidly cooled from above the 1520° F. minimum hot working temperature to below about 1100° F. to retain the maximum amount of nitrogen in solution. It is necessary to cool quickly to below about 1100° F. to preclude any significant precipitation of nitrogen. If the steel is not rapidly cooled, excessive precipitation of nitrogen will occur which will reduce the ductility. The steel is usually descaled by pickling to prepare it for subsequent cold reduction. After cleaning as desired, the steel is cold rolled to the finishing gauge, i.e. desired final thickness, less the reduction due to extension in temper rolling. Cold working the aluminum-killed steel elongates the grains and produces a typically flat, pancake-like, grain structure.

Cold rolling also fractures the grain structure formed during hot rolling and develops strain in the steel. The steel is annealed following cold rolling to relieve the strains and to provide an elongated grain structure wherein the grains are not larger than ASTM No. 7. During annealing, aluminum nitride is precipitated at the grain boundaries and forms an envelope surrounding the grains which restricts grain growth during annealing so that the desirable small-grained structure is produced.

Grain size is usually determined by viewing a polished planar section which has been prepared in such a way as to delineate the grain boundaries. The American Society for Testing Materials has established a standard grain size chart used in industry to standardize grain size descriptions. The designation in the ASTM Chart range from -3 to 10 with the negative and smaller numbers referring to larger sizes. The size of the grains is denoted by three measurements: (1) the number of grains/in.² of image at 100× magnification, (2) the number of grains/mm.², and (3) the number of grains per cubic millimeter. The designation of the coarsest grains in the chart, -3, refers to a structure in which there are 0.06 grains/in.² of image at 100× magnification, one grain/mm.², and/or 0.7 grains per cubic millimeter. The grain structure having ASTM No. 1 contains one grain/in.² of image at 100× magnification, 16 grains/mm.², and 45 grains per cubic millimeter.

The grain structure of steel produced by my invention must have the grain size of not larger than ASTM No. 7, that is to say the grain structure must have an ASTM number of 7, 8, 9 or 10. This designation refers to a grain structure in which there are at least 64 grains/in.² of image at 100× magnification, 1024 grains/mm.², and/or 23,000 grains per cubic millimeter.

At annealing temperatures, there is a tendency for grains to increase in size. By effecting the nitride precipitation during annealing, the growth of the grains can be controlled and limited. Thus, whereas precipitation of nitrogen must be restricted during hot rolling, it is required subsequent to cold reduction to obtain the desired grain structure. Annealing is preferably conducted at above about 1200° F. to accomplish complete nitride precipitation relatively quickly. The maximum aluminum-nitride precipitation occurs at approximately 1300 to 1350° F. and at these temperatures only a few minutes is required for substantially complete precipitation whereas above and below this temperature range more time is required to achieve complete precipitation.

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The final processing step of my treatment is cold rolling of the steel to increase its yield strength and obtain the desired physical and mechanical properties. Cold reduction, i.e. temper rolling, to about a 2% extension of the steel beyond its original length is generally adequate to achieve a yield strength of at least about 35,000 p.s.i. The product produced as described above will have a utility sufficiently high to enable obtaining a 32% minimum elongation in two inches.

The following example illustrates the practice of the invention to produce steel strip useful for many applications.

An aluminum-killed steel melt was nitrogenized by the addition of sufficient calcium cyanamide to produce a final nitrogen content of 0.012% by weight. The steel had the following composition:

	Percent
Carbon	.10
Manganese	.48
Phosphorus	.010
Sulfur	.020
Iron	.014
Copper	.06
Nickel	.02
Chromium	.03
Aluminum	.05
Nitrogen	.012

After solidification into ingots, the steel was rough rolled to slabs. The slabs were heated to a temperature between 2200 to 2250° F. for two hours in which time the nitrogen was substantially completely dissolved. The slabs were then hot rolled on a continuous hot strip mill to a finishing temperature of 1560° F. In hot rolling, the slab thickness was reduced from 5.50 inches to a thickness of 0.187 inch. The steel was then continuously pickled to remove hot rolling scale and rapidly cooled through the nitrogen precipitation range to 1020° F. It was then cold reduced from 0.187 inch thick to 0.125 inch thick and oiled for box annealing. The cold rolled steel was box annealed at a minimum temperature of 1260° F. and baked for 20 hours. The steel coil was removed from the box annealing furnace and after cooling to about 115° F., temper rolled to a 2% extension. The product produced had a yield strength greater than 35,000 p.s.i., and grain structure such that the grains were not larger than ASTM No. 7. The material was ductile and was capable of a 35% elongation in two inches.

I claim:

1. A method of processing steel to produce a substantially non-aging, ductile product comprising:

(A) adding to a melt of aluminum-killed steel which

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has a carbon content of at least 0.08%, not more than 0.6% manganese and not more than 0.02% silicon, a nitrogen-bearing compound in an amount to provide a final nitrogen content in the steel of from 0.008 to 0.015% by weight and then solidifying said melt,

(B) substantially completely dissolving said nitrogen in said steel by maintaining said steel at nitrogen-dissolution temperature,

(C) hot rolling said steel at a temperature above about 1520° F.,

(D) rapidly cooling the hot rolled steel to a temperature below about 1100° F. to minimize precipitation of aluminum-nitride and thereafter cold reducing said steel,

(E) annealing said cold reduced steel for a time sufficient to obtain a recrystallized, elongated grain structure wherein the grains are not larger than ASTM No. 7 and to precipitate aluminum-nitride around said grains whereby the growth of said grains during annealing is restricted by said aluminum-nitride, and

(F) temper rolling to increase the yield strength of the steel.

2. A method according to claim 1 wherein said nitrogen is dissolved in said steel at a temperature of at least about 2200° F.

3. A method according to claim 1 wherein the cold reduced steel is annealed at a temperature in the range of about 1200° F. to 1300° F.

4. A method according to claim 1 wherein said steel is temper rolled to about a 2% extension to provide a yield strength of at least about 35,000 p.s.i. and an elongation of over 32% in 2 inches.

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