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METHOD OF PRODUCING HIGH STRENGTH THIN STEEL

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This invention relates to a method of manufacturing thin steel of high strength and good ductility. It is more particularly concerned with a method of making such steel in which the steel is nitrided either before or after it is reduced to gauge.

Inexpensive thin sheet steel and strip of high strength and good ductility is a desirable article of commerce, particularly as a base for tin plate. Thin steel in the form of wire also has many uses. For reasons of cost steel strip to be tinned is conventionally made of low carbon steel containing no deliberately added alloying elements. The strip is hot rolled to intermediate gauge and is brought to the desired gauge by cold rolling. Those skilled in the art are aware that the degree of reduction of the steel obtained in cold rolling has a great influence on the physical properties of the product, and adjust the relative reductions effected by hot and cold rolling accordingly.

The bulk of the tin plate used in tin cans has thicknesses on the order of .010". The cold rolling necessary to reduce the steel to that gauge also reduces its ductility undesirably and it is therefore conventional in the production of steel of that type to anneal the cold reduced material to soften it. The annealing, of course, reduces the tensile and yield strengths of the material. Conventional tin plate displays tensile strengths of about 45,000 to 50,000 p.s.i. and elongations of about 20 to 25% in two-inch gauge length. Those properties are adequate for conventional tin cans.

Can manufacturers would use even thinner tin plate if its tensile strength were sufficiently higher than conventional material to compensate for the thinner walls of cans made therefrom. Thinner tin plate weighs less and costs less than conventional tin plate per unit of area. Modern rolling mills can roll strip to the thinner gauges desired but the strip after annealing displays very nearly the same unit tensile strength as conventional material and does not produce cans of the required strength.

It is an object of my invention to provide a method of manufacturing steel strip or sheet of light gauge and of unit tensile strength and yield strength substantially higher than that of conventional material. It is another object to provide a method of manufacturing such steel having unimpaired deformability. Other objects of my invention will appear from the description thereof which follows.

I have found that if nitrogen-containing carbon steel in the form of strip, sheet or wire is cold reduced to an intermediate gauge, and is then annealed and further cold reduced to the desired gauge, the resulting product possesses high tensile strength and yield strength and substantial deformability. I have found that if the nitrided steel is cooled after annealing so as to retain its nitrogen in solution, its tensile strength is further increased by strain-aging. I have also found that the steel can be nitrided while it is being annealed.

The desired improvement in tensile strength of the steel is inversely proportional to its thickness. If tin plate .007" thick, for example, is to be manufactured into cans having the same strength as those made from conventional tin plate .010" thick, the tensile strength of the thinner steel must be about 65,000 to 70,000 p.s.i. My invention makes it possible to obtain that improvement in tensile strength without decrease in deformability of the material, and is capable of producing thin material having even higher tensile strengths. My invention also makes it possible to provide thin steel of conventional gauge but with improved tensile and yield strength.

In all cases the steel to which I refer herein is plain carbon steel of the composition range shown in Table I.

<table>
<thead>
<tr>
<th>Carbon, percent</th>
<th>Manganese, percent</th>
<th>Phosphorus, percent</th>
<th>Sulphur, percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>.06-.14</td>
<td>.25-.65</td>
<td>.003</td>
<td>.005</td>
</tr>
</tbody>
</table>

In one embodiment of my process presently preferred by me the steel is worked by hot rolling followed by cold rolling to an intermediate gauge. The material is then annealed in coil form in a non-oxidizing atmosphere to which is added about 25% by volume of anhydrous ammonia. In order that the nitriding of the steel be accomplished uniformly the wraps of the coiled strip must be disposed so that the nitriding atmosphere has access to the entire surface of the coil. In this condition the coil can be simultaneously annealed and nitrided quite rapidly, the time required depending on the temperature to which the steel is heated. I find the temperature range from about 1000° F. to 1200° F. to be satisfactory, the corresponding times ranging from about one-half hour to two hours. Under those conditions the nitrogen content of the steel ranged from about .010% to .030%. The annealed and nitrided strip was cooled to room temperature and brought to the desired final gauge by a further cold reduction of about 2½%.

Those skilled in the art will understand that the treatment above described can be given the steel in the form of sheets if the sheets are disposed during annealing and nitriding so that the furnace atmosphere has access to the entire surface thereof.

Steel strip rolled to nominal .0061" thickness treated as above described exhibits tensile strength of about 76,000 lbs. p.s.i. and ductility, as measured by elongation over a two-inch gauge length, between 6 and 12%. The tensile strength of the material provided by my process is somewhat better than that of conventional material of .018" nominal thickness made from rephosphorized steel. The ductility of the conventional material, measured as elongation over a two-inch gauge length, was about 18%.
When the material produced by my process was aged by dipping it in molten tin at a temperature of 650° F. for five seconds, its tensile strength was increased to about 80,000 lbs. p.s.i.

The process of my invention may also be practiced in another preferred embodiment by continuously annealing and nitriding steel strip or wire in the form of strand. The time during which the steel is at annealing and nitriding temperature is much shorter in continuous strand annealing than in coil annealing so that the temperature of the strand must be increased somewhat. Because of the short time for nitriding, I accomplish this step in an atmosphere of undiluted anhydrous ammonia. Where the steel is held at maximum temperature for at least 30 seconds, a treating temperature of about 1100° F. to about 1300° F. is satisfactory and raises the nitrogen content of the steel to .07% and upward.

The strand was raised to temperature in times ranging from 15 to 36 seconds, held at temperature for 30 seconds, and then cooled. Steel in the form of strand can be cooled rapidly, or quenched, which is not possible for steel in coil form. I find that it is desirable to control the strand to a temperature of about 200° F. or so in about 30 seconds. Steel processed as above described exhibits tensile strengths on the order of 68,000 to 70,000 p.s.i. and elongations between 6 and 19% over a two-inch gauge length. The same material treated in the same way but without nitriding exhibits tensile strength on the order of 56,000 lbs. p.s.i. When the nitried steel is given a further reduction of 2½ to 3% and aged one hour at the temperature of boiling water its tensile strength is increased another 3,000 to 4,000 p.s.i. without significant impairment of its ductility.

It is desirable to have the nitrogen dissolved in the steel rather than precipitated as nitrides. Quenching the steel after annealing and nitriding holds the nitrogen in solution, but aging the steel causes nitrogen to precipitate. Steel wires nitried and annealed as above described and then quenched in water were found to contain 0.30% nitrogen in solution, while wires of the same steel treated in the same way but allowed to age at 200° C. for a week were found to contain only .005% to .008% nitrogen in solution. The wires before aging displayed tensile strengths of 45,000 to 48,000 p.s.i., while after aging their tensile strengths dropped to 40,000 to 41,000 p.s.i.

It is observed that when the quenched material is strain-aged—that is, given a light reduction and then aged, its tensile strength is further increased, as has been mentioned, and its nitrogen remains largely in solution.

It is convenient to nitride the steel at the same time it is being annealed and this procedure makes possible the attainment of much higher nitrogen contents in the steel than can be readily obtained by adding nitrogen to the steel when it is melted. However, steel which is nitrogenized during its melting is satisfactory for my process as long as its nitrogen is not combined with aluminum or like elements known in the art which prevent it from going into solution in the steel. I designate nitrogen in steel suitable for my process as uncombined nitrogen.

The final cold working of my steel includes reductions up to about 15%. I find that value to be critical as far as the deformability of the steel is concerned. I measure deformability by bending a coupon of the material, cut transverse to the rolling direction, 180° around a diameter equal to its original gauge. Table II identifies the effect of various degrees of final reduction of steel of my invention and shows that above about 15% reduction the number of bends which the steel withstands is halved.

The steel of Table II had a composition within the limits of Table I and contained .010%–.012% uncombined nitrogen. It was hot and cold reduced to .0195% thickness, and annealed in coils. It is apparent from Table II that this steel of adequate deformability having tensile strength well over 70,000 p.s.i. is readily attainable by the method of my invention.

It is also apparent from Table II that my method requires a minimum of about .010% uncombined nitrogen in the steel. While smaller amounts will produce some strengthening effect, that effect will not be sufficient within the critical limit of final cold reduction to increase the tensile strength in inverse proportion to the reduced thickness of the steel. Higher nitrogen contents make it possible to obtain the desired strengthening with smaller amounts of final cold reduction.

The reduction effected by cold rolling must be more than about 3% if the yield strength of the material is to be increased. This again may be seen from the data of Table II. The minimum reduction varies slightly with the composition of the steel and its thickness, but it must be more than a conventional temper reduction to bring about a useful increase in yield strength of the material.

I claim:

1. The method of producing thin carbon steel of high yield and tensile strength and substantial deformability comprising annealing cold reduced steel of intermediate gauge containing up to about .14% carbon and at least .010% uncombined nitrogen and then cold reducing the annealed intermediate gauge steel in amount more than about 3% but not more than about 15% to the desired gauge.

2. The method of producing thin carbon steel of high yield and tensile strength and substantial deformability comprisingannealing cold reduced steel of intermediate gauge containing up to about .14% carbon and at least about .010% uncombined nitrogen so that the nitrogen is held in solution in the steel and then cold reducing the annealed intermediate gauge steel in amount more than about 3% but not more than about 15% to the desired gauge.

3. The method of producing thin carbon steel of high tensile strength and substantial deformability comprising cold reducing carbon steel containing up to about .14% carbon to an intermediate gauge, annealing the cold reduced steel in a nitriding atmosphere so as to nitride the steel to at least about .010% uncombined nitrogen content, and then cold reducing the annealed intermediate gauge steel in amount more than about 15% to the desired gauge.
4. The method of claim 3 in which the steel is annealed and nitrided in coil form at a temperature between about 1000° F. and 1200° F. in a non-oxidizing atmosphere containing anhydrous ammonia.

5. The method of claim 3 in which the steel is continuously annealed and nitrided in the form of strand at a temperature between about 1100° F. and 1300° F.

6. The method of claim 3 in which the steel is quenched after annealing and before cold reducing to the desired gauge.

7. The method of claim 5 in which the strand is held at temperature in an atmosphere of anhydrous ammonia for at least about 30 seconds, and then cooled.

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