Feb. 12, 1957 W. KALITA 2,781,283

METHOD OF PROCESSING STAINLESS STEELS

Filed Oct. 3, 1955

Fig. 1

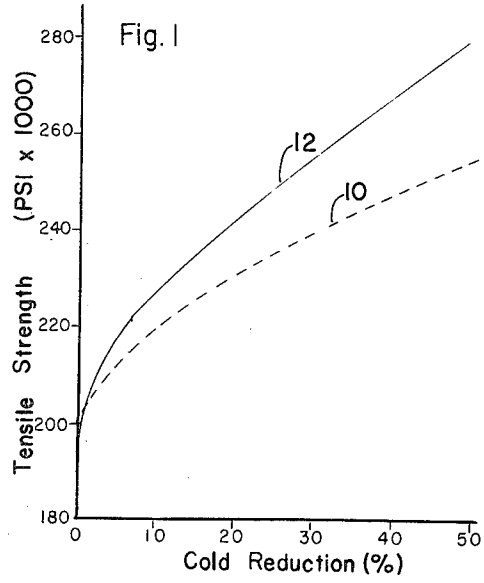


Fig. 3

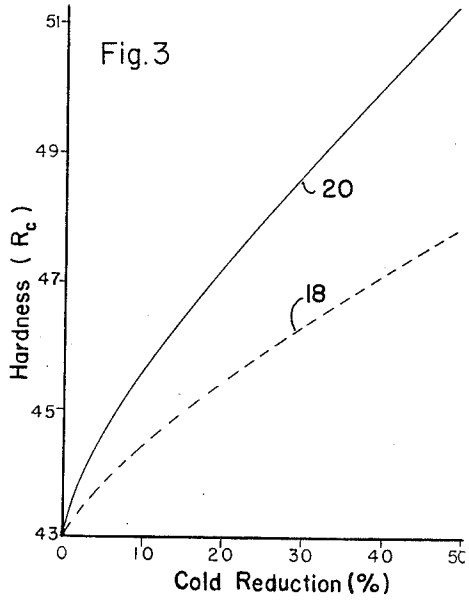


Fig. 2

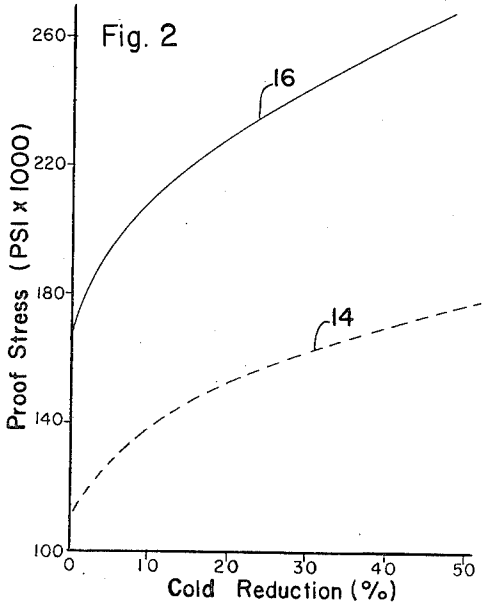
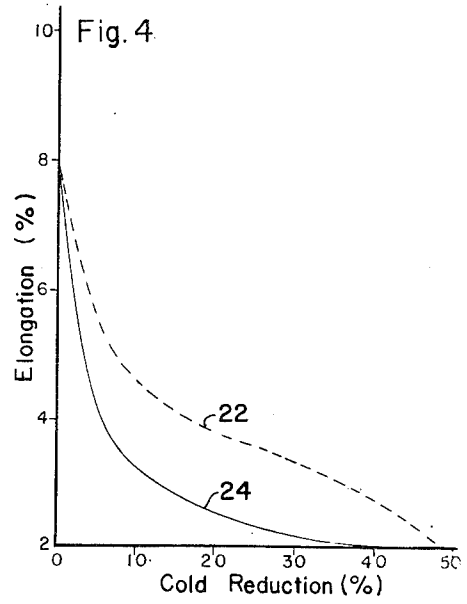


Fig. 4



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METHOD OF PROCESSING STAINLESS STEELS

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8 Claims. (Cl. 148—12.4)

This invention relates to a method of processing stainless steel and in particular to a method of processing stainless steel of the AISI types 410 and 420.

AISI type 410 and type 420 stainless steels are martensitic stainless steels which can be hardened through heat treatment. These steels are especially useful when fabricated into cutlery products, springs and the like. In applications in the cutlery field, it is necessary for these steels to possess a high hardness in order to maintain a sharp cutting edge, have a high elasticity or proof stress in order to permit flexing of the steel without the steel taking a permanent set, and the finished product must usually have a bright surface finish in order to be acceptable. In addition, the steel must be substantially free from internal stresses which would distort the steel during fabrication such as a blanking operation or during the grinding of a cutting edge on the steel.

At present it is possible to commercially obtain an AISI type 410 stainless steel having a hardness of between 43 R_c and 45 R_c. This degree of hardness is produced in the final product after the steel is subjected to a number of high temperature annealing treatments in which the steel is slowly cooled from the annealing temperature in order to soften it to thereby permit a sufficient number of cold reductions to reduce the steel to within 0.001 inch of the thickness of the final product. After the steel is cold reduced, it is hardened by heating to a temperature above the critical temperature and quenching therefrom. The hardened steel is cold rolled to the finish thickness by a reduction in the thickness of 0.001 inch maximum, the sole purpose of which is to flatten the steel. It has been found, however, that while the commercially available prior art steels possess a hardness of between 43 R_c and 45 R_c, the hardness is lower than the hardness desired by the fabricators of cutlery items. In addition, the proof stress is also substantially lower than desired.

An object of this invention is to provide a method for processing AISI type 410 and type 420 stainless steels to impart high hardness and excellent proof stresses thereto.

Another object of this invention is to provide a method for processing AISI type 410 and type 420 stainless steels in which the final product is substantially free from internal stresses and has a bright surface finish thereon.

A more particular object of this invention is to provide a method for producing AISI type 410 and type 420 stainless steel containing from a small but effective amount up to 0.25% maximum carbon, 11% to 14.5% chromium, and the balance substantially iron with incidental impurities, in which the steel is cast into ingots and hot worked to an intermediate product, the intermediate product thereafter being subjected to a number of alternate subcritical normalizing and cold reducing steps followed by a hardening, final cold rolling and stress relief annealing treatments to produce a resultant product having a high hardness, excellent proof stress and bright surface finish and which is substantially free from internal stresses.

These and other objects of this invention will become apparent from the following description when taken in conjunction with the accompanying drawing in which:

Figure 1 is a graph, the curves of which show the effect of increasing the amount of the final cold reduction to the finish thickness of the final product on the tensile strength of a hardened AISI type 410 stainless steel before and after stress relief annealing;

Fig. 2 is a graph, the curves of which show the effect of increasing the amount of the final cold reduction to the finish thickness of the final product on the proof stress of the steels of Fig. 1;

Fig. 3 is a graph, the curves of which show the effect of increasing the amount of final cold reduction to the finish thickness of the final product on the hardness of the steels of Fig. 1; and

Fig. 4 is a graph, the curves of which show the effect of increasing the amount of final cold reduction to the finish thickness of the final product on the percentage elongation of the steels of Fig. 1.

In its broader aspects the process of this invention contemplates producing a melt of AISI type 410 or type 420 martensitic stainless steel, casting the melt into ingots, hot working the ingots into an intermediate product, subcritically normalizing the hot worked intermediate product, cold reducing the normalized intermediate product to within 10% to 40% of the finish thickness of the final product in one or more cold reducing operations with a subcritical normalizing treatment interposed between each of the cold reducing operations, heating the cold reduced material above the critical temperature to harden it, cold reducing the hardened material to the finish thickness of the final product and thereafter stress relief annealing the final product with the result that the final product has a hardness of at least 46 R_c minimum, a proof stress in excess of 180,000 p. s. i., a bright surface finish with good reflectivity and substantial freedom from internal stresses.

More particularly, the AISI type 410 and type 420 martensitic stainless steel to which the process of this invention is applied is made in the usual manner as is well known in the stainless steel making art. AISI type 410 stainless steel contains up to 0.15% maximum carbon, 11.0% to 13.5% chromium, about 1% maximum manganese, about 1% maximum silicon and the balance iron with up to 1.5% of incidental impurities of the type normally found in the production of these steels, for example, nickel, cobalt, copper, sulphur, phosphorus and the like. The AISI type 420 stainless steel contains more than 0.15% carbon, 12% to 14.5% chromium and the balance iron with up to 1.5% of incidental impurities of the type usually found in the production of such steels such as nickel, cobalt, copper, sulphur, phosphorus and the like. It is desirable when applying the process of this invention to the AISI type 420 stainless steel to limit the carbon content to 0.25% maximum in order to eliminate any cold rolling difficulty which may be encountered in applying the process of this invention to AISI type 420 stainless steel, as will be more fully explained hereinafter.

Since the production of AISI type 410 and type 420 stainless steel is well known in the steel making art it will not be described here in detail. After the melt of stainless steel has been refined to obtain the desired analysis, the melt is cast into ingots in the well-known manner. The ingots are soaked at a temperature of about 2300° F. which is in excess of the critical temperature and thereafter they are hot worked usually by rolling to the desired intermediate product having a thickness usually although not necessarily in the range

between 0.100 inch and 0.200 inch. The hot rolled intermediate product may be any of the well-known semi-finished mill products, for example, sheet, strip, wire, bar and the like.

Since the steel has been hot rolled at a temperature in excess of the critical temperature and allowed to air cool therefrom, the hot rolled intermediate product will harden upon cooling as is the well-known phenomenon which occurs with martensitic type stainless steels of which the AISI type 410 and type 420 are common examples. Since the steel is in its hardened condition it must be softened in order to cold work the steel to the desired thickness. In order to soften the steel, the prior art practices advert to the use of a box annealing treatment wherein the hot rolled intermediate product is heated to a temperature in excess of the critical temperature and thereafter the steel is slowly cooled. This has usually resulted in a steel having a hardness of approximately 80 R_b. The box annealed steel, being in the soft condition, is then cold rolled in one or more cold rolling operations to within at least 0.001 inch in thickness of the finish thickness of the final product.

Contrary to the teachings of the prior art, the process of this invention does not make use of the box annealing treatment. Instead, the hot rolled intermediate product is subjected to a subcritical normalizing treatment consisting of heating the hot rolled intermediate product to a temperature in the range between 1200° F. and 1500° F., which temperature is below the critical temperature, and thereafter cooling the steel in air. Since the temperature of the subcritical normalizing treatment is below the critical or transformation temperature, the steel will not harden when air cooled because there is no phase transformation involved. The effect of the subcritical normalizing treatment is to produce a softening of the steel and a recrystallization of the grain structure without any phase transformation. It is preferred to subcritically normalize the hot rolled intermediate product by passing the hot rolled intermediate product through a continuous normalizing furnace in which the temperature is maintained within the range of between 1200° F. and 1500° F. The speed at which the hot rolled intermediate product is moved through the normalizing furnace is adjusted in such a manner that the hot rolled intermediate product is at the subcritical normalizing temperature for a time period ranging between 45 minutes and 75 minutes per inch of thickness of the hot rolled intermediate product. This results in the normalized product being softened to a hardness within the range between 25 R_c and 30 R_c. The optimum subcritical normalizing treatment consists of passing the hot rolled intermediate product through a continuous normalizing furnace at a temperature in the range between 1250° F. and 1300° F. with the speed of the material adjusted so that the hot rolled intermediate product being normalized is at the normalizing furnace operating temperature for about 60 minutes per inch of thickness of the hot rolled intermediate product. The normalized product usually has a hardness in the range between 25 R_c and 30 R_c which is sufficiently soft to permit a cold reduction of between 10% and 60% in the thickness as will be more fully described.

It is to be noted that with the use of a continuous subcritical normalizing treatment a more efficient and faster heat treatment is applied to the hot rolled intermediate product resulting in a considerable savings in the processing costs. Furthermore, since the steel being normalized is at the elevated temperature of the normalizing operation for a relatively short time, depending upon the thickness of the hot rolled intermediate product, scaling is held to a minimum. Moreover, while a protective atmosphere can be used, no protective atmosphere is needed for the normalizing heat treatment used in the process of this invention. The normalized intermediate product is usually subjected to a pickling or descaling operation to remove any scale that may have been formed during the normalizing heat treatment and cooling from the hot rolling temperature. However, since scaling is held to a minimum as stated hereinbefore, a considerable savings is realized in the pickling or descaling cost over that encountered in following the prior art box anneal practice.

Since the steel has a clean surface and is in the soft, ductile condition it is readily cold reduced to within 10% to 40% of the thickness of the final product. This is usually accomplished by cold roll reducing the flat products, for example, sheet, strip or bar, or by cold drawing as in the case of wire. The cold reduction of the normalized and pickled intermediate product to within 10% to 40% of the thickness of the final product may be accomplished in one or more operations. If more than one cold reduction is applied to these steels, a subcritical normalizing and pickling or descaling treatment similar to those previously described are interposed between each cold reduction operation.

More particularly, the normalized and pickled intermediate product is subjected to one or more cold reducing operations in which the thickness of the steel is reduced between 10% and 60% of the starting thickness of the steel in each cold reducing operation. It has been found that these steels respond to the process of this invention for providing the requisite hardness, proof stress and surface finish when the thickness of the starting material in each cold reduction operation is reduced as little as 10%. Smaller reductions in thickness however will not produce the desired optimum properties while materially increasing the processing costs.

It has been found desirable when applying the process of this invention to AISI type 420 stainless steel to limit the carbon content to 0.25% maximum because larger carbon contents render it difficult to cold reduce this type of steel at least 10%, which amount, especially in the final cold reduction to the finish thickness of the final product of both type 410 and 420 steel as will be explained more fully hereinafter, is necessary to make the steel respond to the process of this invention to obtain the desired physical properties in the final product.

Reductions of up to 60% in thickness can be economically accomplished in type 410 and 420 steel when the steel has a hardness of between 25 R_c and 30 R_c after having been subcritically normalized. However, a 60% reduction in thickness has been found to be the upper practical limit to which the thickness of these steels can be cold reduced before work hardening becomes excessive and the cost of further processing the steel without a softening treatment becomes prohibitive. While it would seem that the box annealed steel of the prior art would permit a greater measure of cold reduction before requiring a softening treatment because it has a substantially lower hardness than the hardness of the subcritically normalized steel of the process of this invention, such has not been found to be the case. Furthermore, when the prior art box annealing is used to soften the steel either after hot rolling to the intermediate product or between reducing operations where more than one cold reducing operation is required, the final product does not develop the desired hardness nor the proof stress desired in these types of steels when they are used, for example, in the cutlery field.

The cold reduction of the subcritical normalized and pickled AISI type 410 stainless steel must be acomplished in such a manner that the steel is reduced in thickness to within 10% to 40% of the finish thickness of the final product. While this may be accomplished in one or more cold reducing operations with a subcritical normalizing and pickling operation interposed therebetween, it is essential that the last cold reduction operation prior to a hardening treatment and final cold reduction, to be described hereinafter, reduces the thickness of the steel at least 10% and to within 10% to 40% of the finish thickness of the final product. More specifically, it has been found that the optimum balance between economics and excellent physical properties is obtained

when the thickness of the steel is cold reduced at least 10% in thickness in the last cold reduction operation prior to the hardening treatment referred to and that such cold reduced steel have a thickness of between 20% and 30% in excess of the finish thickness of the final product.

In order to provide the steel with a bright surface finish, it is desirable when cold reducing flat products to use highly polished work rolls for reducing the steel during the cold reducing operations. While highly polished work rolls can be used in each cold rolling operation, it is only necessary that the last cold rolling operation prior to the hardening treatment to be more fully described, and the final cold roll reduction to the finish thickness of the final product subsequent to hardening, be conducted on the highly polished work rolls in order to obtain the desired bright surface finish. In practice it has been found that when the steel is cold reduced on highly polished work roll as above described, the final product has a surface reflectivity of at least 40%.

When the thickness of the cold reduced stainless steel is within the range between 10% and 40% greater in thickness than the finish thickness of the final product, the steel is hardened by heating to a temperature within the range between 1700° F. and 1875° F. and air cooling from the hardening temperature. Since the AISI type 410 and 420 stainless steel are martensitic stainless steels, and the temperature of the hardening treatment is above the critical temperature, these steels, when air cooled from the temperature of the hardening treatment, will transform to the martensite phase and exhibit a substantial increase in the hardness. It is preferred to continuously harden the cold reduced steel by passing the steel through a continuous hardening furnace which is operated at a temperature in the range between 1700° F. and 1875° F. The speed of the steel is so regulated that it is at the hardening temperature for a time period of between 30 minutes and 65 minutes per inch of thickness of the cold reduced steel. After air cooling, the steel has a hardness in the range between 43 R_c and 46 R_c. While the hardening furnace is not necessarily supplied with a protective atmosphere, nevertheless a protective atmosphere or a surface treatment atmosphere may be used where desired. Since the steel is at the hardening temperature for a relatively short period of time, depending upon the thickness, scaling is not too severe. A light pickling or descaling operation suffices to remove the scale and provide the steel with a clean surface. An optimum hardening treatment consists of continuously subjecting the cold reduced steel to a temperature in the range between 1700° F. and 1800° F. for a time period of about 60 minutes per inch of thickness of the cold reduced steel followed by air cooling to impart a hardness of about 44 R_c minimum to the hardened stainless steel.

The hardened steel is then cold reduced to the finish thickness of the final product by a final cold reduction operation applied in either one step or in a plurality of substantially continuous steps without any intermediate heat treatment therebetween. Thus the steel may pass between a pair of reversing rolls a number of times or a number of tandem rolls or may be drawn through a series of wire dies whatever the case may be, without heat treatment therebetween in effecting the 10% to 40% final cold reduction to the finish thickness of the final product. In practice it has been found desirable when cold rolling the hardened steel to the finish thickness of the final product to apply such cold reduction on rolls which are provided with a circle crown of about .004 to .006 inch in a 20 inch roll in order to obtain optimum flatness in the final product. Where the steel is to be provided with a bright surface finish, the final cold reduction treatment to reduce the hardened steel to the finish thickness is accomplished by rolling the steel using highly polished work rolls or drawing through highly polished dies as in the case of wire. The cold reduction to the finish thickness of the final product will increase the hardness of the previously hardened steel about 1 to 4 points R_c depending upon the amount of cold reduction to the finish thickness. Such final cold reduction treatment to the finish thickness, however, is found to introduce high internal stresses in the steel having the finish thickness with the result that if such steel were to be blanked or a cutting edge ground thereon, the steel would warp and distort.

In order to relieve the internal stress imposed by the final cold reduction in thickness of 10% to 40% to the finish thickness of the final product, the hardened and cold reduced steel is subjected to a stress relief annealing at a temperature in the range between 700° F. and 1100° F. It has been found that such an anneal not only removes the internal stresses of the hardened, cold reduced steel of the finish thickness but also effects an increase in the hardness of the steel of from 2 to 8 points R_c over the hardness of the steel after the final cold reduction to the finish thickness. While the reason for the increase in the hardness occasioned by the low temperature stress relief annealing is not completely understood, it is believed that the steel, being in the stressed condition resulting from the cold reduction after the hardening treatment, has some internal energy which cooperates with the energy available during stress relief annealing in such a manner that the steel will possess sufficient energy to transform the unstable retained austenite which had not been previously transformed during the cooling from the hardening temperature, to martensite.

The preferred stress relief annealing consists of heating the hardened and cold reduced steel of the finish thickness at a temperature in the range between 750° and 900° F. The stress relief annealing is conveniently accomplished by passing the steel through a continuous stress relief annealing furnace operating at a temperature in the range indicated for a time period ranging between 45 minutes and 75 minutes per inch of thickness of the finish thickness. In practice, optimum properties have resulted after stress relief annealing in which the steel is continuously heated to a temperature within the range between 800° F. and 850° F. for a time period of about 60 minutes per inch of thickness of the final thickness. It is desired to maintain the stress relief annealing temperatures near the lower end of the range in order to minimize scaling during such annealing treatment.

In order to more clearly demonstrate the process of this invention, reference may be had to the following schedule of a typical example of commercial mill processing of a heat of AISI type 410 stainless steel for use as a knife blade having a thickness of 0.060 inch.

(1) Heat No. 343473 melted in an electric arc furnace, the melt being refined to produce a steel having an analysis of about 0.14% carbon, about 12.88% chromium, about 0.65% manganese, about 0.45% silicon and the balance iron with incidental impurities.

(2) Cast the melt into ingots.

(3) Hot roll the ingots to strip 0.160 inch in thickness.

(4) Continuously subcritically normalize the hot rolled strip at a temperature between 1250° F. and 1300° F. for about 9½ minutes and air cool (strip hardness 26 R_c).

(5) Descale or pickle.

(6) Cold roll reduce normalized and pickled strip about 25% to 0.120 inch in thickness.

(7) Continuously subcritically normalize cold roll reduced strip at a temperature between 1250° F. and 1300° F. for about 7 minutes and air cool (strip hardness 26 R_c).

(8) Descale or pickle.

(9) Cold roll reduce strip from step 7 and/or step 8 about 33% to 0.080 inch in thickness on highly polished work rolls. (Note: This thickness of 0.080 inch permits a final 25% cold reduction to finish thickness of 0.060 inch.)

(10) Continuously harden cold roll reduced strip at a temperature in the range between 1700° F. and 1800° F. for about 5 minutes (strip hardness 44 Rc).

(11) Final cold roll 25% to finish thickness of 0.060 inch using highly polished work rolls (strip hardness 45 Rc).

(12) Continuously stress relief anneal strip at a temperature between 800° F. and 850° F. for approximately 3½ minutes (strip hardness 48 Rc, proof stress 222,200 p. s. i.).

As another example of the process of this invention, the following steps were performed on steel from the same heat in order to produce a final product for use as a spatula blade having a thickness of 0.018 inch:

(1) (Same as step 1 in previous example.)

(2) (Same as step 2 in previous example.)

(3) Hot roll the ingot to strip 0.125 inch in thickness.

(4) Continuously subcritically normalize the hot rolled strip at a temperature between 1250° F. and 1300° F. for about 7½ minutes and air cool (strip hardness 26 Rc).

(5) Descale or pickle.

(6) Cold roll reduce the normalized and pickled strip about 56% to 0.055 inch thickness.

(7) Continuously subcritically normalize cold roll reduced strip at a temperature of between 1250° F. and 1300° F. for about 3 minutes and air cool (strip hardness 26 Rc).

(8) Descale or pickle.

(9) Cold roll reduce steel strip from steps 7 and/or step 8 about 56% to 0.024 inch in thickness on highly polished work rolls. (Note: This thickness of 0.024 inch permits a final cold reduction of about 25% to finish thickness of 0.018 inch.)

(10) Continuously harden cold roll reduced strip at a temperature between 1700° F. and 1800° F. for about 1½ minutes (strip hardness 44 Rc).

(11) Final cold roll 25% to finish thickness of 0.018 inch using highly polished work rolls (strip hardness 45 Rc).

(12) Continuously stress relief anneal strip of finish thickness at a temperature between 800° F. and 850° F. for about 1 minute (strip hardness 48 Rc, proof stress about 230,000 p. s. i.).

In each of the foregoing examples, the steel, after processing, had an excellent tensile strength, hardness, proof stress, ductility and bright surface finish, while being free from internal stresses. It is apparent that the process of this invention has produced a steel having highly superior properties when compared to those processed by prior art practices.

In order to more clearly demonstrate the outstanding results obtained through the use of the process of this invention, reference may be had to Figs. 1 through 4 of the drawings. Fig. 1 of the drawings illustrates the effect of increasing the amount of final cold reduction applied to the previously reduced and hardened steel on the tensile strength of an AISI type 410 stainless steel which was subjected to the process of this invention. The test results which are plotted to form curve **10** illustrates the effect of varying the amount of the final cold reduction on the tensile strength of type 410 stainless steel which was cold reduced but not subjected to a stress relief anneal, whereas curve **12** illustrates the effect of varying the amount of final cold reduction on the tensile strength on the same steel and which was thereafter stress relief annealed. It is apparent when comparing curves **10** and **12** that as little as a 10% final cold reduction to the finish thickness effects a substantial increase in the tensile strength of the steel as cold reduced and also as cold reduced and stress relief annealed. However, it is clearly evident that substantially higher tensile strengths are obtainable when the steel is stress relief annealed following the final cold reduction to finish thickness. Furthermore, the final cold reduction and stress relief annealing treatments appear to cooperate in imparting highly superior tensile strengths to these steels when they are treated according to the process of this invention. In contrast to such results, steel processed according to the prior art teachings is known to have a tensile strength of approximately only 200,000 p. s. i. or the value where curve **10** intersects the ordinate of Fig. 1. While it would appear from the curves of Fig. 1 that substantially higher physical properties can be obtained when the final cold reduction to the finish thickness of the final product exceeds a 40% reduction in thickness, it has been found that 40% is the maximum final reduction in thickness which can be economically applied to the hardened type 410 or type 420 stainless steel. For example, in order to increase the final reduction applied to the hardened steel (see step 10 of the examples) from a 20% reduction in thickness to a 30% reduction in thickness, about 2 to 3 passes are usually required on a 4-hi cold rolling mill, whereas to increase the final reduction applied to the hardened steel from a 40% reduction in thickness to a 50% reduction in thickness, about 6 to 9 passes are usually required on the same 4-hi cold rolling mill. The optimum cold reduction to the finish thickness is from 20% to 30% when viewed from the economic standpoint consistent with excellent physical properties. While final reductions in excess of 40% are physically possible, they are not commercially feasible.

The curves of Fig. 2 illustrate the effect of increasing the amount of final cold reduction to the finish thickness of the final product on the proof stress of a hardened type 410 stainless steel which was treated the same as the steel for the curves of Fig. 1. Curve **14** illustrates the effect of increasing the amount of the cold reduction to the finish thickness of the final product on the proof stress for the cold reduced steel of curve **10** of Fig. 1, and curve **16** illustrates the effect of increasing the amount of the cold reduction to the finish thickness of the final product on the proof stress of the stress relief annealed steel of curve **12** of Fig. 1. It is apparent from curve **14** that there is an increase in the proof stress occasioned by as little as a 10% reduction in thickness to the finish thickness of the final product. However, upon stress relief annealing following the cold reduction to the finish thickness, the proof stress increases a tremendous amount as illustrated by curve **16**. The increase in the proof stress is outstanding when compared to the proof stress of approximately only 110,000 p. s. i. obtained on steels processed according to the prior art teachings or the approximate value of the intersection of curve **14** with the ordinate of Fig. 2. As the amount of the final cold reduction increases from 10% to 40% the amount of the increase in the proof stress upon stress relief annealing far surpasses the amount of the increase in the proof stress occasioned by merely cold rolling without the benefit of a stress relief anneal as shown by curves **16** and **14** respectively. For the reasons set forth hereinbefore, the amount of cold reduction is limited to 40% of the thickness to the finish thickness of the final product, even though greater cold reductions would appear to further increase the proof stress. In all cases it has been found that with as little as 10% reduction in the thickness to the finish thickness of the final product followed by a stress relief annealing, AISI type 410 and type 420 stainless steels when processed according to this invention possess a proof stress in excess of 180,000 p. s. i.

The effect of increasing the amount of the cold reduction on the hardness of type 410 stainless steel is illustrated in Fig. 3 in which curve **18** illustrates the effect of increasing the amount of the final cold reduction treatment to the finish thickness of the final product on the hardness for the steels of curve **10** of Fig. 1, and curve **20** illustrates the effect of increasing the amount of the final cold reduction treatment to the finish thickness of the final product on the hardness of the steels of curve **12** of Fig. 1 as stress relief annealed. It is apparent from

curves 18 and 20 that when the steel is cold reduced after the hardening treatment to the finish thickness of the final product that the hardness is increased with increasing amounts of cold reduction, as is particularly demonstrated by curve 18. However, as illustrated by curve 20, the same steel having the same amount of cold reduction has been found to substantially increase in hardness after stress relief annealing following the cold reduction operation. As was stated hereinbefore, it is believed this increase in hardness is due to the steel having sufficient internal energy after cold reduction, together with the energy supplied by the stress relief annealing treatment to transform the unstable austenite upon cooling from the hardening treatment to martensite and thereby increase the hardness. As can be seen from curve 18, cold reductions of up to 40% increase the hardness about 4 points Rc over that of the steel subjected to the heat hardening treatment. Since this steel has increased in hardness because of the high internal stresses due to work hardening imposed by the cold reduction to the finish thickness of the final product, a further cold reduction is attained only with much difficulty, as was stated hereinabove. Even though greater reductions than 40% in thickness to the final product would substantially increase the physical properties thereof, 40% is the maximum reduction in the thickness which can be applied economically.

Likewise, as is evident from curve 20, a substantial increase in the hardness is obtained where the steel is subjected to a final cold reduction of between 10% and 40% followed by a stress relief anneal. For example, where the steel is subjected to a final reduction of 40% to the finish thickness of the final product and stress relief annealed, the hardness increases from about 43 Rc for the steel as hardened by heat treatment to a hardness of about 50 Rc. It is further to be noted that when the steel is subjected to a final cold reduction of 10% followed by the stress relief anneal that an effective increase in hardness of about 3 points Rc is obtained over the hardness of 43 Rc for the steel as hardened by heat treatment. The combination of the final cold reduction of between 10% and 40% followed by the stress relief anneal produces an outstanding increase in the hardness of the steel when the process of this invention is applied to the AISI type 410 and 420 stainless steels. The improvement obtained in the hardness of the steel by practicing the process of this invention is quite evident when it is considered that with the prior art practice of box annealing and cold rolling the material to within about 0.001 inch in thickness of the finished thickness followed by hardening heat treatment and a skin pass to effect a reduction of not more than 0.001 inch to flatten the resulting steel, such steel has a hardness usually of not more than about 43 Rc.

While it is apparent that there is a great increase in the tensile strength, proof stress, and hardness when the steels are cold reduced up to 40% and thereafter stress relief annealed, yet the same steels after processing possess sufficient ductility as illustrated in Fig. 4 to prevent them from being brittle. Curve 22 of Fig. 4 illustrates the effect of increasing the amount of cold reduction to the finish thickness of the final product on the percentage elongation on the steel of curve 10 of Fig. 1, and curve 24 illustrates the effect of increasing the amount of the cold reduction to the finish thickness of the final product on the percentage elongation for the steel of curve 10 of Fig. 1 as stress relief annealed. It is apparent from Fig. 4 that as the amount of cold reduction increases, the ductility as measured by the percentage elongation is decreased. It is seen from curves 22 and 24, respectively, that the cold reduced steel without stress relief annealing has a slightly higher percentage elongation than the steel which has been cold reduced and stress relief annealed. This phenomenon would seem to follow because of the reasons for increase in the tensile strength and especially the proof stress and hardness upon stress relief annealing. It must be pointed out, however, that in all cases, the steel, when treated by the process of this invention, always has a ductility as measured by the percentage elongation of at least 2% when the alloy is cold rolled as much as 40% and thereafter stress relief annealed. Since the process of the invention always imparts to the steel an elongation of at least 2%, the steel is free from brittleness. The freedom from brittleness is extremely important because when these steels are fabricated, for example by blanking, punching or stamping, into the form of the finished product such as a knife blade which is intended for use as a household cutlery item, any brittleness in the processed steel would prevent it from being formed to the consumer item and would also make the consumer item useless for any practical application.

From the foregoing discussion and the graphs of Figs. 1 through 4 it is apparent that the process of this invention is effective for increasing the tensile strength, proof stress and hardness without too great a sacrifice in the ductility of the steel.

There are no special skills or apparatus required to perform the process of this invention. Conventional heat treatment furnaces which are common in the steel industry are used completely throughout the process of this invention. It is to be especially noted that no protective atmospheres are needed during the heat treatments, but such atmospheres may be used where desired without departing from the spirit of this invention. The physical properties obtained as a result of the process of this invention are readily reproducible and substantially uniform when the process of the invention is applied to substantially similar heats of steel. The heat treatment temperatures are substantially lower than those of the prior art processes and heat treatment times are substantially shorter, thereby effecting considerable savings in both time and materials. The finished steel has an excellent surface finish, is free from internal stresses, has an excellent proof stress, high hardness, high tensile strength and sufficient ductility to prevent it from being brittle.

I claim:

1. In the method of producing stainless steel having a high hardness, high proof stress and substantial freedom from internal stresses from a hot worked intermediate product formed from an ingot having a composition comprising up to 0.25% maximum carbon, about 11.0% to about 14.5% chromium, and the balance substantially iron with incidental impurities, the steps comprising, subjecting the intermediate product to a subcritical normalizing treatment at a temperature in the range between 1200° F. and 1500° F., cold reducing the normalized intermediate product to effect a reduction therein of between 10% to 60% such that the thickness of the cold reduced intermediate product is within 10% to 40% of the finished thickness of the final product, heating the cold reduced intermediate product at a temperature in the range between 1700° F. and 1875° F., cooling to harden the product, cold reducing the hardened cold reduced intermediate product 10% to 40% to the finish thickness of the final product, and stress relief annealing the final product at a temperature in the range between 700° F. and 1100° F., the final product being characterized by having a hardness of 46 Rc minimum and a proof stress in excess of 180,000 p. s. i.

2. In the method of producing stainless steel having a high hardness, high proof stress and substantial freedom from internal stresses from a hot worked intermediate product formed from an ingot having a composition comprising up to 0.25% maximum carbon, about 11.0% to about 14.5% chromium, and the balance substantially iron with incidental impurities, the steps comprising, subjecting the intermediate product to a continuous subcritical normalizing treatment by heating it to a temperature in the range between 1200° F. and 1500° F. for a time period ranging between 45 minutes and 75 minutes per inch of thickness of the normalized intermediate

product, cold reducing the normalized intermediate product to effect a reduction therein of between 10% and 60% such that the thickness of the cold reduced intermediate product is within 10% to 40% of the finished thickness of the final product, continuously hardening the cold reduced intermediate product by heating it to a temperature in the range between 1700° F. and 1875° F., for a time period ranging between 30 minutes and 65 minutes per inch of thickness of the cold reduced intermediate product to harden the product cooling, cold reducing the hardened cold reduced intermediate product to the finish thickness of the final product, and continuously stress relief annealing the final product at a temperature in the range between 700° F. and 1100° F., for a time period ranging between 45 minutes and 75 minutes per inch of thickness of the final product, the final product being characterized by having a hardness of 46 R_c minimum and a proof stress in excess of 180,000 p. s. i.

3. In the method of producing stainless steel having a high hardness, high proof stress and substantial freedom from internal stresses from a hot rolled intermediate product having a thickness in the range between 0.100 and 0.200 inch formed from an ingot having a composition comprising up to 0.15% maximum carbon, about 11.0% to about 13.5% chromium, and the balance substantially iron with incidental impurities, the steps comprising, subjecting the intermediate strip product to a continuous subcritical normalizing treatment at a temperature in the range between 1250° F. and 1300° F., for a time period of about 60 minutes per inch of thickness of the hot rolled intermediate strip product to obtain a hardness in the strip in the range between 26 R_c and 30 R_c, cold roll reducing the normalized intermediate strip product to effect a reduction in thickness therein of between 10% and 60% such that the thickness of the cold roll reduced intermediate strip product is within 20% to 30% of the finish thickness of the final product, continuously hardening the cold roll reduced intermediate strip product by heating at a temperature in the range between 1700° F. and 1800° F. for a time period of about 45 minutes per inch of thickness of the cold roll reduced intermediate strip product and cooling to produce a hardness in the range between 43 R_c and 47 R_c therein, cold roll reducing the hardened cold roll reduced intermediate strip product to the finish thickness of the final product, and continuously stress relief annealing the final strip product at a temperature in the range between 800° F. and 850° F. for a time period of about 60 minutes per inch of thickness of the final strip product to remove the internal stresses therefrom, the final strip product having a hardness in the range between 48 R_c and 54 R_c and a proof stress in excess of 215,000 p. s. i.

4. In the method of producing stainless steel having a high hardness, high proof stress and substantial freedom from internal stresses from a hot worked intermediate product formed from an ingot having a composition comprising up to 0.25% maximum carbon about 11.0% to about 14.5% chromium, and the balance substantially iron with incidental impurities, the steps comprising, subjecting the intermediate product to a subcritical normalizing treatment at a temperature in the range between 1200° F. and 1500° F., cold reducing the normalized intermediate product to a size within 10% to 40% of the finish thickness of the final product, such cold reduction being effected in a plurality of steps with a normalizing treatment between each of said steps, each of the cold reductions effecting a reduction of between 10% to 60% of the thickness of the starting material of each step, the last of said cold reductions effecting a reduction to within 10% to 40% of the finish thickness of the final product, the normalizing treatment between each of the cold reductions being a subcritical normalizing treatment at a temperature in the range between 1200° F. and 1500° F., subjecting said cold reduced material to a temperature in the range between 1700° F. and 1875° F., cooling to harden it, cold reducing the hardened cold reduced material to the finish thickness of the final product, and stress relief annealing the final product at a temperature in the range between 700° F. and 1100° F., the final product being characterized by having a hardness of 46 R_c minimum and a proof stress in excess of 180,000 p. s. i.

5. In the method of producing stainless steel having a high hardness, high proof stress and substantial freedom from internal stresses from a hot worked intermediate product formed from an ingot having a composition comprising up to 0.25% maximum carbon, about 11.0% to about 14.5% chromium, and the balance substantially iron with incidental impurities, the steps comprising, subjecting the intermediate product to a continuous subcritical normalizing treatment by heating it to a temperature in the range between 1200° F. and 1500° F. for a time period ranging between 45 minutes and 75 minutes per inch of thickness of the hot worked intermediate product, cold reducing the normalized intermediate product to a size within 10% to 40% of the finish thickness of the final product, such cold reduction being effected in a plurality of steps with a normalizing treatment between each of said steps, each of the cold reductions effecting a reduction in thickness of between 10% and 60% of the thickness of the starting material of each step, the last of said cold reductions effecting a reduction to within 10% to 40% of the finish thickness of the final product, the normalizing treatment between each of the cold reductions being a continuous subcritical normalizing treatment at a temperature in the range between 1200° F. and 1500° F. for a time period ranging between 45 minutes and 75 minutes per inch of thickness of the cold reduced steel, subjecting said cold reduced steel to a continuous hardening treatment by heating at a temperature in the range between 1700° F. and 1875° F. for a time period ranging between 30 minutes and 65 minutes per inch of thickness of the cold reduced steel and cooling to harden it, cold reducing the hardened cold reduced steel to the finish thickness of the final product, and continuously stress relief annealing the final product at a temperature in the range between 700° F. and 1100° F. for a time period ranging between 45 minutes and 75 minutes per inch of thickness of the final product, the final product being characterized by having a hardness of 46 R_c minimum and a proof stress in excess of 180,000 p. s. i.

6. In the method of producing stainless steel having a high hardness, high proof stress and substantial freedom from internal stresses from a hot rolled intermediate product having a thickness in the range between 0.100 and 0.200 inch formed from an ingot having a composition comprising up to 0.15% maximum carbon about 11.0% to about 13.5% chromium, and the balance substantially iron with incidental impurities, the steps comprising, subjecting the hot rolled intermediate strip product to a continuous subcritical normalizing treatment by heating the strip to a temperature in the range between 1250° F. and 1300° F. for a time period of about 60 minutes per inch of thickness of the hot rolled intermediate strip product to soften it to a hardness in the range between 25 R_c and 30 R_c, cold roll reducing the normalized intermediate strip product to a thickness within 10% to 40% of the finish thickness of the final strip product, such cold roll reduction being effected in a plurality of operations with a normalizing treatment between each of said cold roll reducing operations, each of the cold roll reductions effecting a reduction of between 10% to 60% of the thickness of the starting strip material of each cold roll reducing operation, the last of said cold roll reductions being accomplished on highly polished work rolls and effecting a reduction to within 20% to 30% of the finish thickness of the final strip product, the normalizing treatment between each of the cold roll reductions being a continuous subcritical normalizing treatment at a

temperature in the range between 1250° F. and 1300° F. for a time period of about 60 minutes per inch of cold roll reduced strip thickness to soften the strip to a hardness in the range between 25 R_c and 30 R_c, subjecting said cold roll reduced strip material to a continuous hardening treatment by heating at a temperature in the range between 1700° F. and 1800° F. for a time period of about 45 minutes per inch of thickness of the cold roll reduced strip material and cooling to harden it to a hardness in the range between 44 R_c and 46 R_c, cold roll reducing the hardened strip material using highly polished work rolls to the finish thickness of the final strip product, and continuously stress relief annealing the final product at a temperature in the range between 800° F. and 850° F. for a time period of about 60 minutes per inch of thickness of the final strip product to remove the internal stresses therefrom, the final product being characterized by having a hardness of 48 R_c minimum, a proof stress in excess of 215,000 p. s. i. and a bright surface finish having a reflectivity of at least 40%.

7. In the method of producing stainless steel having a high hardness, high proof stress and substantial freedom from internal stresses from a hot rolled intermediate product having a thickness of about 0.160 inch formed from an ingot having a composition comprising about 0.14% carbon, about 12.88% chromium and the balance substantially iron with incidental impurities, the steps comprising, subjecting the hot rolled intermediate strip product having a thickness of about 0.160 inch to a continuous subcritical normalizing treatment by heating it to a temperature in the range between 1250° F. and 1300° F. for a time period of about 9½ minutes to soften the steel to a hardness of about 26 R_c, pickling the normalized intermediate strip product to remove the scale therefrom and provide the strip with a clean surface, cold roll reducing the normalized and pickled intermediate strip product about 25% to a thickness of about 0.120 inch, subjecting the cold roll reduced intermediate strip product to a continuous subcritical normalizing treatment by heating it to a temperature in the range of 1250° F. and 1300° F. for a time period of about 7 minutes to soften the strip product to a hardness of about 26 R_c, pickling the cold roll reduced and normalized strip product to remove the scale therefrom, cold roll reducing the normalized and pickled strip product to within about 25% of the thickness of the final product by reducing the thickness of the normalized and pickled strip product about 33% to a thickness of about 0.080 inch using highly polished work rolls, subjecting said cold reduced strip product to a continuous hardening treatment by heating at a temperature in the range between 1700° F. and 1800° F. for about 5 minutes and cooling to harden it to a hardness of about 44 R_c, cold roll reducing the

hardened strip product on highly polished work rolls about 25% to the finish thickness of about 0.060 inch of the final strip product, and continuously stress relief annealing the final strip product at a temperature in the range between 800° F. and 850° F. for a time period of about 3½ minutes to remove the internal stresses therefrom, the final strip product being characterized by having a bright surface finish, a hardness of about 48 R_c, and a proof stress of about 222,200 p. s. i.

8. In the method of producing stainless steel having a high hardness, high proof stress and substantial freedom from internal stresses from a hot rolled intermediate product having a thickness of about 0.125 inch formed from an ingot having a composition comprising about 0.14% carbon, about 12.88% chromium and the balance substantially iron with incidental impurities, the steps comprising, subjecting the hot rolled intermediate strip product having a thickness of about 0.125 inch to a continuous subcritical normalizing treatment by heating it to a temperature in the range between 1250° F. and 1300° F. for a time period of about 7½ minutes to soften the steel to a hardness of about 26 R_c, pickling the normalized intermediate strip product to remove the scale therefrom and provide the strip with a clean surface, cold roll reducing the normalized and pickled intermediate strip product about 56% to a thickness of about 0.055 inch, subjecting the cold roll reduced intermediate strip product to a continuous subcritical normalizing treatment by heating it to a temperature in the range of 1250° F. and 1300° F. for a time period of about 3½ minutes to soften the strip product to a hardness of about 26 R_c, pickling the cold roll reduced and normalized strip product to remove the scale therefrom, cold roll reducing the normalized and pickled strip product to within about 25% of the thickness of the final product by reducing the thickness of the normalized and pickled strip product about 56% to a thickness of about 0.024 inch using highly polished work rolls, subjecting said cold reduced strip product to a continuous hardening treatment by heating at a temperature in the range between 1700° F. and 1800° F. for about 1.5 minutes and cooling to harden it to a hardness of about 44 R_c, cold roll reducing the hardened strip product on highly polished work rolls about 25% to the finish thickness of about 0.018 inch of the final strip product, and continuously stress relief annealing the final strip product at a temperature in the range between 800° F. and 850° F. for a time period of about 1 minute to remove the internal stresses therefrom, the final strip product being characterized by having a bright surface finish, a hardness of about 48 R_c, and a proof stress of about 230,000 p. s. i.

No references cited.