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METHOD OF PRODUCING ARTICLES HAVING A CUTTING EDGE PORTION AND CONSISTING OF STAINLESS CHROMIUM STEEL

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The present invention relates to a method of producing knife blades of stainless chromium steel, preferably with a hypereutectoid initial structure, which have an increased cutting power and edge life.

This is a continuation-in-part of the co-pending patent application Serial No. 730,783, filed April 25, 1958, now abandoned.

The cutting power and edge life of knife blades, particularly of stainless steel, depend in the first place on the presence of a matrix structure of slightly tempered martensite of high hardness and in the second place on the embedding of a sufficient number of finely and uniformly distributed carbides in this matrix. It is necessary to void a crumbling of the carbides at the edge of the knife, as will occur in the case of an excessively coarse and insufficiently uniform distribution. However, the carbides in themselves have no usefulness, unless the matrix has a high hardness and an extremely high resistance to squeezing and wear. This statement is corroborated by the extreme counterexample of a soft-annealed steel, which contains a very large number of carbides in a fine and uniform distribution, which are embedded in a matrix that has been intentionally softened. Such soft-annealed steel is known for a very low wear resistance. For this reason the martensitic matrix is very important for knife blades. However, because the matrix is solely responsive for the springlike toughness and the impact resistance, it must also satisfy requirements which in themselves oppose those calling for the highest possible hardness.

Various methods have previousely been adopted for increasing the cutting power and edge life. In the first place it has been attempted to increase the carbon content of the stainless steel in order to increase the proportion of hard chromium carbides in the structure. Other carbide-forming alloying constituents such as molybdenum, tungsten, vanadium, titanium and the like have been added in economically tolerable amounts. The destruction of the unfavorable lattice arrangement of the carbides which is present in the ingot is promoted by the hot forming from the ingot to the knife blade. This hot forming, which is substantial in any case will cause a destruction of the carbide lattice and uniformization of the carbide distribution, although this is not always fully satisfactory.

The quenching treatment is of special importance. It has previously been known to heat stainless martensitic chromium steels to an austenitizing temperature which is relatively high, i.e. approximately 150° C. and sometimes eventually higher, above transformation temperature before quenching in order to dissolve an adequate quantity of the chromium carbides in the austenite and to obtain therefrom a hard martensite having a sufficiently high chromium content. It must not be overlooked, however, that this measure is only called for by necessity and involves substantially disadvantages. It is a generally known fact that the formation of austenite of very fine grain, which after quenching produces a martensite in the form of finest needles, having the least brittleness and being ideal in a certain sense, i.e. martensite with the finest needle structure and highest hardness, as well as

relatively best toughness, is ensured only when the steel is heated only for a short time and only slightly above the transformation temperature into the austenitic range, i.e. to about 50° C. and in no case more than 100° C. above the transformation temperature. Any higher or prolonged heating will inevitably cause a smaller or greater increase in the coarseness of the austenitic grain and will result during the subsequent quenching in a martensite consisting of coarser needles and having a higher brittleness. In the case of the real material a moderate tempering, which involves only a small loss in hardness, is sufficient to ensure an excellent toughness with a high elastic limit. On the other hand, coarser and brittler martensite must be more highly tempered to achieve a sufficient toughness. This will inevitably lower the elastic limit and, on principle, also the hardness. For this reason the high austenitizing temperature which was previously usual for stainless martensitic chromium steels can only be considered an undesirable measure, which is required by the need to dissolve a sufficient amount of chromium carbides.

The above could be opposed by the statement that the hypereutectoid chromium carbides embedded in the structure of stainless chromium steels hinder the growth of the austenite grain so that such steels will tolerate a greater temperature rise above the transformation temperature than carbon steels without an excessive growth of the austenitic grain.

Experience has taught, however, that this assumption is only partly correct; in fact, the chromium carbides inhibit the growth only to a restricted degree. Steels which are actually almost insusceptible in a wide range to overheating in the austenitic range can only be produced, by experience, if the melt is mixed with extremely fine (mainly submicroscopic) nuclei of alumina or titanium oxide or similar substances, which are inert to the austenite itself; these are the known fine-grained steels. On the other hand, the chromium carbides in stainless chromium steels can produce an analogous effect only to a restricted and insufficient degree because they are in a state of coarse dispersion and are not inert with respect to the austenite but are partly dissolved by it.

For this reason it must be maintained that even in stainless chromium steels any substantial overheating above the transformation temperature into the austenitic range will cause a coarsening of the austenite grain, with all detrimental consequences described herein before the martensite resulting from the subsequent quenching. Whereas this method can eventually produce a hard martensite, the finished tempered workpiece, particularly the knife, does not show the desired toughness and elastic limit. Because the toughness and the elastic limit are important factors for the wear characteristics and consequently for the cutting power and edge life, it has not been possible to obtain optimum values for these properties of the workpieces, although these properties are often decisive in practice.

Thus a previously unsolved problem in connection with stainless martensitic chromium steels resides in the desire to provide a method which eliminates the need for a high austenitizing temperature, i.e. a temperature highly in excess of the transformation temperature during the heating before quenching, and a prolonged maintenance of the austenitizing temperature, and which nevertheless ensures the dissolution of a sufficient amount of chromium carbides in the austenite. This means that it is desired to produce an austenite which has a high chromium content and yet has no coarse structure and which produces a martensite in the form of fine needles of high hardness as a result of the subsequent quenching, which martensite when moderately tempered with a low loss of reduction in hardness will produce a finished steel having a high

elastic limit and good toughness and, therefore, a good wear resistance. This would ensure the desired high cutting power and edge life desired in the case of knives.

From U.S. Patent No. 2,266,952 to Bloom, it is known to introduce a cold-forming operation in the treatment of stainless steel. This known process, however, differs basically from the subject matter of the present invention in the object aimed at and in the sequence of treatments. Its object is to achieve a higher elastic limit in stainless steel and spokes or automobile wheels and similar resilient components and are expressly mentioned as preferred applications whereas there is no reference whatever to articles having a cutting edge, such as knives, and to their cutting power and edge life. This known method comprises first quench-hardening the stainless steel, then cold-forming the quench-hardened steel to an appropriate degree by drawing or flexing and finally tempering the steel. It is said that it has been found that the cold-forming between quench-hardening and tempering causes a considerable increase in the elastic limit as is desired for the above-mentioned applications.

As contrasted therewith it is one object of the present invention to facilitate and enhance the dissolution of the carbides during quench-hardening in order to increase the cutting power and edge life of the knives.

It is another object of the present invention to provide a method of producing knife blades of stainless chromium steel, wherein the blades produced by hot-forming (hot rolling, hot forging) are subject to cold-forming in the cutting edge portion before quench-hardening and are subsequently heated only for a short time to a quenching temperature which is only slightly above the transformation temperature. These measures enforce slip in the atomic space lattice and increase the latent energy content of the space lattice. The heating only slightly above the transformation temperature and a very short timing at the temperature thus obtained, will result in a much higher proportion of chromium carbides in the austenite than would result from an otherwise similar treatment unless the space lattice has been activated by the preceding cold forming. The subsequent quenching will produce the desired martensite in the form of very fine needles. As contrasted with the previous procedure, this martensite has higher carbon and chromium contents and, therefore, a much higher hardness. Owing to the fact that the martensite is in the form of very fine needles, a moderate tempering will produce a good spring toughness without excessive reduction in hardness. Thus the knife blades thus treated have a higher wear resistance and an increased cutting power and edge life than the knife blades obtained by the previously usual procedure, whereas they are in no way inferior in toughness to the previously made knife blades.

In addition to the improvement in quality achieved by the process according to the present invention, the latter improves also the manufacturing technology because a lower austenitizing temperature and a shorter heating time will obviously facilitate the entire treatment. In addition, the preceding cold forming and the lower temperature rise result in a cleaner surface of the workpieces. This partly improved destruction of the carbides and uniformization of their distribution as a result of the cold forming are additional, not insignificant improvements afforded by the process according to the present invention.

It is a further object of the present invention to provide a new, successful procedure for the treatment of knife blades of stainless chromium steel, which procedure is based on a very general law of nature, namely, the increase in the energy content and the activation of a crystalline aggregation by cold forming. The success was not foreseeable, particularly as regards the essential uniformity of the result, and it was necessary to develop a procedure which has entirely eliminated this objection and which enables a cold forming operation to be introduced before quenching in the sequence of operation with good results.

Tests have shown that the necessary degree of cold-forming is at least at 5%; cold-forming by 10–20% is preferably used for best results. It has also been found that it may be desirable to subject the blades to soft annealing after hot forming and before cold forming. The tests have convincingly confirmed that the cutting power and edge life of knife blades of stainless chromium steels are multiplied by the process according to the present invention compared to knife blades produced by conventional methods. This effect was not to be foreseen. It is known from U.S. Patent No. 2,671,861 to Barnes et al. that the manufacture of gin saw blades is performed by sorbitic hardening of cold-rolled steel. But in making knives from stainless chromium steel, the previous experience in hardening technology has taught that cold forming before quench-hardening should be avoided. On the contrary, a soft annealing treatment is often effected directly before quench-hardening because it is believed that the quench-hardening directly applied to the cold-formed srtucture will cause non-uniform results or give rise to stress cracks. The discovery according to the present invention has shown, however, that these traditional assumptions are not applicable to an orderly manufacture of knives. This enables the activation of the space lattice, i.e. the increase in its latent energy content, by cold forming, causing an increase and acceleration of the dissolution of part of the carbides with the favorable consequences described and without detrimental secondary effects. Especially the lowering of the quenching temperature to the point of achieving martensite of finest needle structure, highest hardness and relatively best toughness, and at the same time with high chromium content, is the practically very important result of the present process.

The cold forming effected between hot forming and quench-hardening promotes also the destruction of the occluded carbides and the uniformization of their distribution in a more energetic manner than is possible by hot forming alone. In view of the favorable result described hereinbefore and resulting in a fine and uniform distribution of the carbides, this means a further improvement in cutting power and edge life. More highly disintegrated carbides will dissolve more easily in the austenite to the extent to which such dissolution is desired and the surplus which is not dissolved in the austenite will never permit a grain to break out at the edge because these carbides are extremely finely and uniformly divided.

Example

The example has been chosen with the manufacture of a stainless steel kitchen knife.

The manufacture was started from a hot-rolled steel rod having a dimension of 20 x 4 mm. with a stainless steel delivered from the steel works corresponding to the material No. 4034 (X 40 Cr 13) which indicated the following analysis: C=0.40%, Si=0.40%, Mn=0.30%, P max. 0.02%, S max. 0.02%, Cr=13.0%, Ni less than 0.5%.

The steel used in this instance had the following composition: C=0.42%, Si=0.36%, Mn=0.33%, P=0.014%, S=0.012%, Cr=13.9%, Ni=0.22%.

The steel rod was cut on the cold shearing machine into sections in correspondence with the weight of the knife blade (plus about 20% addition for losses due to edging off, etc.). The sections were heated in an electric muffle furnace (heating coil furnace) for a period of about 14 minutes to the starting wrought iron temperature of 1050° C. prescribed for this steel by the steel works, the temperature being continuously observed by means of a platinum and platinum-rhodium thermo-couple according to Le Chatelier on a temperature scriber, which thermo-couple is built into the electric muffle furnace. The indi-

vidual steel sections are removed from the furnace by the worker by means of tongs and then immediately stretched and widened to the shape of the knife blade and of the fang by means of a mechanical spring hammer. Since during the hot-forging, the temperature may not fall below 850° C., an after-heating in periods of two minutes each is necessary at least twice, in order to remain in each part and during the total hot formation by forging about within the temperature range of 1050° C. to 850° C.

Of course, the degree of forming is different during the hot forging in the different parts of the knife, which fact may be ascertained from the fact that from the starting cross-section of 20 x 4 mm., a knife blade is formed which, in its widest portion, has the width of 48 mm. and terminates to a point, the thickness on the back-side being reduced from 2.2 mm. to 1.0 mm. and amounts to 0.8 mm. at the point of the edge to be formed. The fang receives a cross-section of 24 x 2 mm. according to the knife handle for the fang made of plastic or wood. The average degree of heat forming during forging of the knife may be set with about 4-times, starting from rolled steel rods. After terminating the hot-forging step the blades are inserted into hot sand, the temperature of which remains steadiy between 250° C. and 400° C., in order to enforce a slow cooling period.

Then the soft annealing of the knife was performed and in order to bring this about, the blades were brought to a temperature of 750° C. again in an electrical muffle furnace having heating coils in packages of 24 each and retained at said temperature for about 3 hours and 20 minutes. Then the electric muffle furnace was reduced to a temperature of about 350° C. within a time period of 4 hours and 30 minutes by switching off the heating current and the soft annealed knives were removed from the furnace at that temperature, to let then the knives cool off in the air to room temperature. The knives are then cut to an exact shape by means of a cold shearing machine and then freed from its gratings received during the forging and annealing process.

While all the steps set forth above follow the conventional and known process for the manufacture of stainless steel knives, now the decisive new phase of the process starts now in accordance with the present invention. This new step resides in the fact that the knife is now formed in its cold state by means of a spring hammer, thus at room temperature of about +20° C., yet its edge portion only. Due to the cold hammer operation, the thickness of the knife edge is reduced from about 0.8 mm. to 0.65 mm., which reduction corresponds to a cold-forming of about 19%. The degree of cold-forming is reduced towards the back of the knife and in particular substantially evenly from 19% to about 5%, which value of 5% is reached about at a distance of 20 mm. from the edge of the knife and still further towards the back of the cold-forming is reduced to zero. Thus, a strip of a width of 20 mm. only from the edge of the knife is within the range of the effective cold-forming of more than 5%. The area of the point of the knife is in this manner within the area of the effective cold-forming. It is quite understood that the knife fang is excluded from any cold-forming.

The described cold-forming creates now the condition that during the following quenching hardening of the knife, the temperature which was required for this step in the conventional process, could be appreciably reduced. The steel works prescribe for the steel mentioned above a quenching temperature of 980° to 1020° C. in oil, which corresponds with a temperature range given also by other steel works for the same type of steel. After boiling in water in order to release the tension and a following heating to about 420° C. for half an hour, in accordance with the instructions of the steel works a Rockwell-C-hardness of the blade of 53 units is to be achieved, which information is also the same in the instructions of other experienced steel works. Due to the particular novel

step, set forth above, namely the preparation of the blade by means of the described cold-forming, the quenching temperature could be held lower for more than 50° C. than the temperature prescribed by the steel works, without interfering in the least with the quality of the knife; rather to the contrary, an appreciable improvement in the quality of the edge of the knife could be found, as will be set forth below. In the present example, the knives were inserted in an electric muffle furnace having heating coils to a temperature of 920° C. This heating took no more time than the heating according to the previous conventional process in the same furnace to the temperature of 980° C. to 1020° C. This temperature is reached in about three minutes. A retaining at the temperature of 920° C., after reaching this temperature was completely avoided, and the knife blades were quenched immediately upon reaching the temperature of 920° C. in oil of 25° C., in the same manner as in accordance with the directions by the steel works, this had to be done at a temperature of 980° C. to 1020° C. Then the boiling in water for releasing the tension took place for 20 minutes, the same as in conventional methods, and the heating for half an hour in an electric muffle furnace at 420° C. with following cooling on the air, thus again without the slightest change of the conventional process.

The following surprising result has been found:

In that portion of the knife blade which has received prior to the quenching step a fold-forming of at least 5% (thus the portion from the edge and up to 20 mm. apart) a Rockwell-C-hardness of 53 to 54 units has been achieved in spite of the lower quenching temperature of only 920° C. Thus, the Rockwell-C-hardness achieved by injecting the novel cold-forming step is the same as previously could be achieved only at a quenching temperature of 980° C. to 1020° C. On the other hand, that portion of the blade in the vicinity of the back thereof, which was not subjected to the preliminary cold-forming step, received during the quenching at a temperature of 920° C. and following conventional heating, only a Rockwell-C-hardness of an average of 48 units, which hardness would be too low for the edge portion of the blade for the cutting ability and for retaining the edge, which low Rockwell-C-hardness is not damaging in the back portion and is, as a matter of fact, desirable since it increases the tenacity of the knife and makes it fracture-proof. From these observations it is quite apparent that only due to the intermediate cold-forming step of at least 5% prior to the quenching step, the decisive, important reduction of the quenching temperature for at least 50° C. is made possible without reducing the hardness of the knife or the edge thereof, which is achieved after an unchanged heating step; in the present example, the reduction of the quenching temperature is even within a range of 60° C. to 100° C., namely from 980° C.–1020° C. down to only 920° C. This unchanged hardness is achieved as a particular additional advantage of the method designed in accordance with the present invention, brought about by the refined quenching and reheating structure achieved by means of the reduced quenching temperature, namely less overheating over the upper transforming point. From this arrangement, an improved tenacity, in spite of at least equal hardness, is also achieved in the edge portion of the knife. Thus, the danger of breaking out of the knife edge is reduced and the wear and the retaining of the edge is improved, since the best wear resistance is brought about by a co-operation of sufficient hardness and tenacity, the latter avoiding the premature tearing off of finest particles of the working material during use. The above-mentioned reduced hardness of the back portion of the knife is of no significance for the cutting ability and retaining of the edge, while if as a whole it contributes to the tenacity of the knife edge. For the purpose of the present invention it is of no significance whether the back portion of the knife

is excluded from the cold-forming step or not. The former is only more suitable and permits, as set forth above, the clear proof of the favorable effect of the combination of the cold-forming step prior to the quenching step with the reduction of the quenching temperature.

A cold-forming after the quenching and heating is outside the scope of the present invention. Such cold-forming step after the quenching step was not applied in the described example.

The results obtained by the present invention may be easily ascertained from the following observations:

The stainless steel knives contain chromium partly in form of chrome-iron-double carbides. If a sufficiently high hardness, as necessary for knife edges, is to be achieved after the quenching step, it is necessary that a sufficient portion of these double carbides is dissolved in gamma-iron, since otherwise the gamma-iron and the martensite formed therefrom after the quenching step, is poor in iron and also too soft. These chrome-iron-double carbides in stainless chrome steels are characterized by a difficult solubility, which is much more severe than that of simple iron carbides in non-alloyed steels. In order to enforce now in stainless steels a sufficient carbide solubility, it is necessary to drive the overheating much higher than the transformation temperature of the gamma-iron, than it would be necessary in non-alloyed steels. The other possible way to extend the retaining of the gamma-iron temperature is not advisable due to the growth of the corn and for other reasons. This leads to the following conditions:

	Forming Temperature of the gamma-iron, ° C.	Conventional heating prior to the quenching in oil	Actual overheating
Conventional stainless knife steel.	825	975° C. (in accordance with directions of many steel works and in the above-described example, even 980° C. to 1,020° C.).	150° C. (even 155° C. to 195° C.).
However: Non-alloyed steel.	735	815° C	Only 80° C.

This necessary overheating was up to now a necessary evil. It led in the stainless knife steels to corn growth and reduction of tenacity, yet it had to be taken as the lesser evil, since a necessary hardness of the knife could not be brought about otherwise.

The present invention applies now the known law of nature, that by means of a cold-forming the latent energy content of a metal is increased in principle. From this the conclusion was reached for the first time, that the increase of solubility, which can be expected from such increase of the latent energy content, could be made to practical use. The tests have confirmed this hope. It could be shown for the stainless knife steel that a limited cold-forming prior to the heating of the steel to quenching temperature has the effect of an appreciable increase of solubility of the chrome-iron-double carbides which is difficult for dissolution in gamma-iron. This means practically that the heating has to be driven to such a high temperature as before, or the overheating over the transformation temperature of the gamma-iron may be reduced and still a fast and extensive soltuion of the chrome-iron-double carbides in gamma-iron may be obtained the same as previously at a higher temperature. Practically, the results seem to be as follows:

	Forming temperature of the gamma-iron	Now necessary heating prior to the quenching in oil	Now provided overheating
Conventional stainless knife steel, yet prior to the heating to quenching temperature of an at least 5% cold-forming (in the example it was given between 19% and 5%).	825° C. (is independent upon the pre-treatment).	maximum 925° C. (in the example it was 920° C.).	maximum 100° C. (in the example it was only 95° C.).

The equally large and equally fast dissolution of the chrome-iron-double carbides leads during quenching to a highly hardened martensite. The appreciably reduced temperature for the heating prior to the quenching leads to a fine corn martensite. In this manner, an optimum combination of hardness and tenacity is brought about, which leads to fracture-proof knives as well as to knives having a high cutting ability. The resistance against wear which is important for the continuous retaining of the edge is particularly improved since it is a function of a high hardness and of a high tenacity. Thus, the present invention is based on the known law of nature, which has not been recognized before and which is now applied in accordance with the present invention.

While I have disclosed one embodiment of the present invention, it is to be understood that this embodiment is given by example only and not in a limiting sense, the scope of the present invention being determined by the objects and the claims.

I claim:

1. A method of producing knife blades of hardenable stainless steel containing at least 13% chromium and having a hypereutectoid initial structure with a carbon content of more than 0.25%, said steel having a cutting edge portion with high wear resistance and good cutting and elastic properties, comprising the steps of hot-forming said blades, thereafter cold-deforming of said cutting edge portion of said blades to a reduction of thickness by at least 5 percent, subsequently heating said blades to a temperature of 50° C. to not more than 100° C. above the austenite forming temperature, and then quenching said blades to the point of achieving martensite.

2. The method, as set forth in claim 1, wherein said knife blades are soft-annealed between said hot forming and said cold forming steps.

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