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M. COHEN

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HEAT TREATMENT OF HIGH SPEED STEELS

Filed Nov. 5, 1940

3 Sheets-Sheet 1

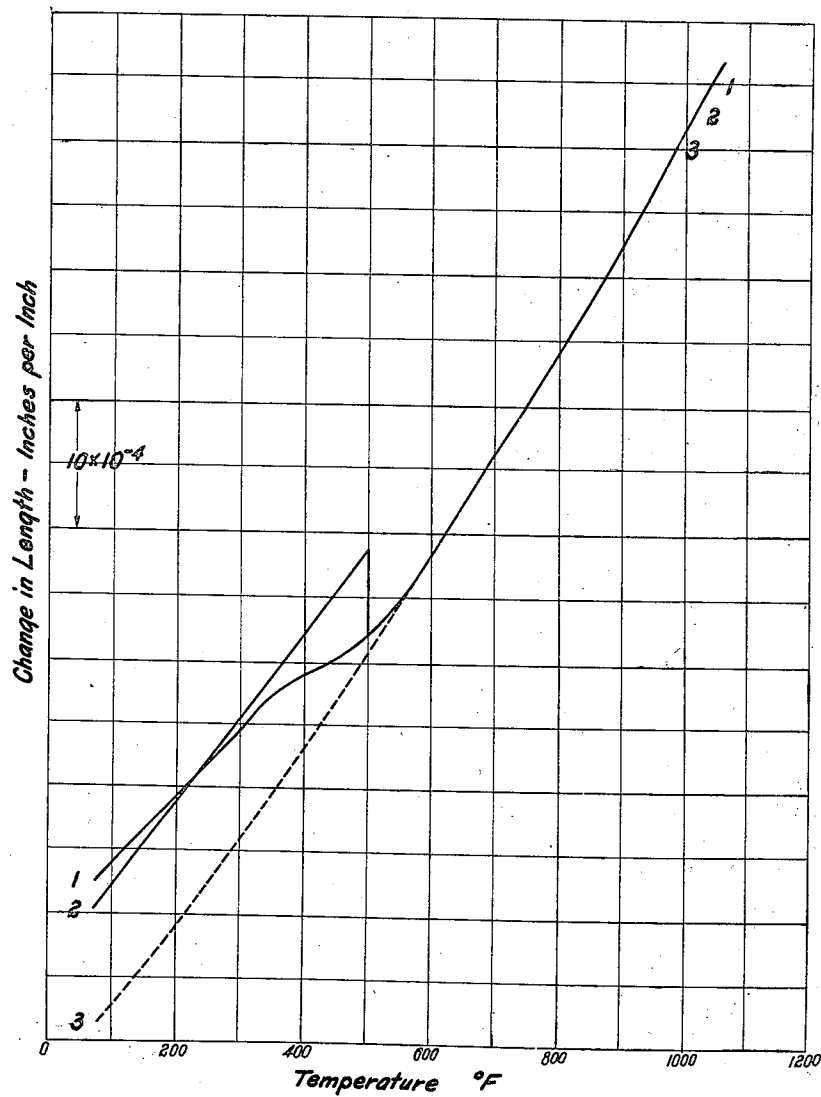


Fig. 1.

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3 Sheets-Sheet 2

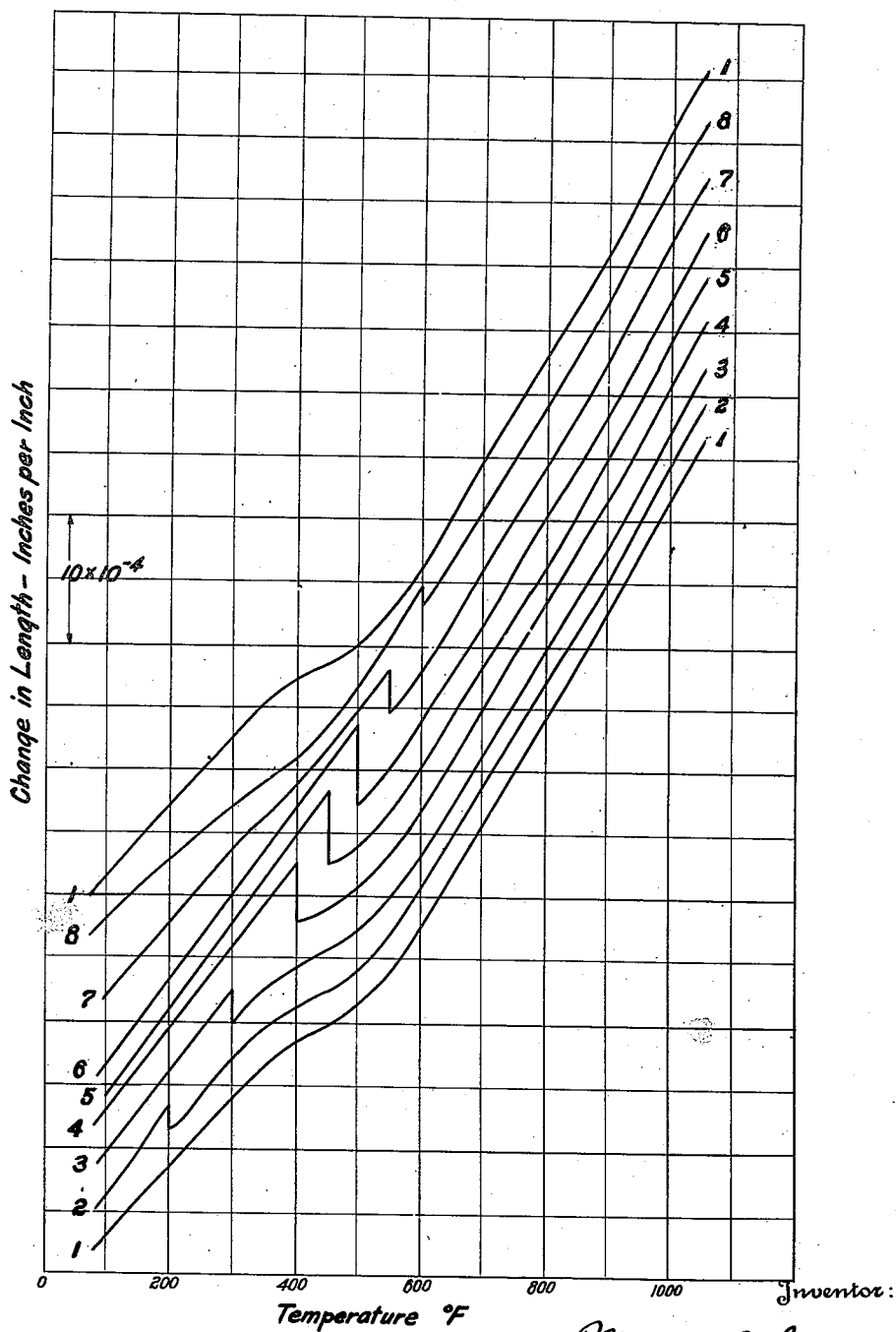


Fig. 2.

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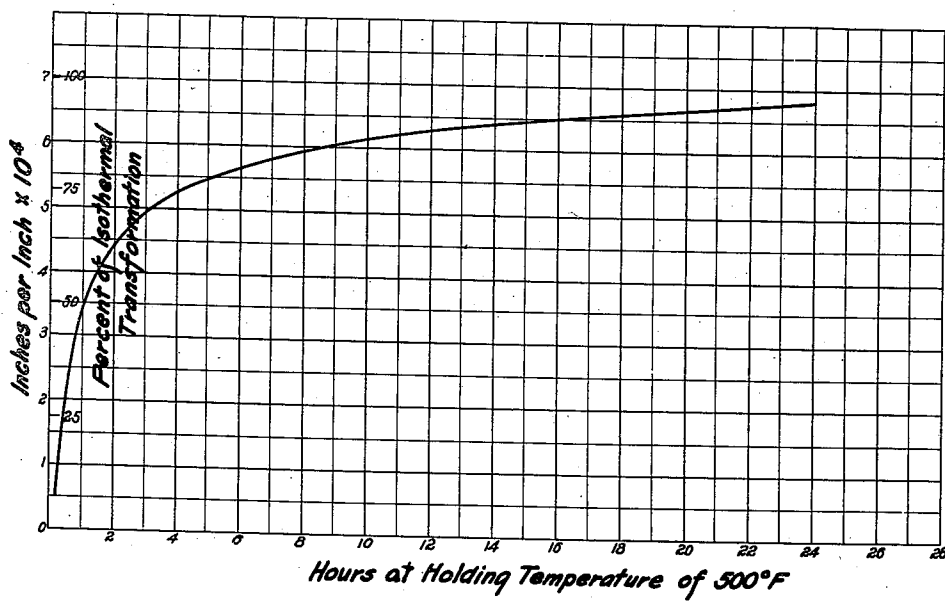


Fig. 3.

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UNITED STATES PATENT OFFICE

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HEAT TREATMENT OF HIGH SPEED STEELS

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10 Claims. (Cl. 148—21.5)

This invention relates to the heat treatment of high speed steels and more particularly to a process involving a controlled—specifically an interrupted—cooling of high speed steels from the tempering temperature.

An object of the invention is to provide a method for the heat treatment of high speed steels which will effectively reduce the internal stresses in articles made of such steels and thereby lessen the damage incident to distortion and cracking in such articles.

Another object of the invention is to provide a method for the heat treatment of high speed steels which will produce more ductile and more shock resistant products than are obtained by customary methods for the heat treatment of such steels.

Still another object of the invention is to provide a method for the heat treatment of high speed steels which will produce less volume change of the metal during the heat treatment than the methods of heat treatment heretofore employed and thereby permit a more accurate control of the size and shape of articles made of such steels.

The customary method for the heat treatment of high speed steels comprises two principal steps called hardening and tempering. The hardening step involves heating the steel at approximately 2100–2400° F. either with or without a preheating at approximately 1400–1600° F., and then cooling to room temperature in oil, or less commonly in air. Occasionally the cooling of the steel from the hardening temperature may be interrupted at approximately 1000° F.–1200° F. During the heating to the hardening temperature the matrix of the steel becomes converted into a relatively soft solid solution known as austenite which partially dissolves the hard complex carbide particles present in such steels. During the cooling of the steel from the hardening temperature this austenite partially transforms into a very hard structure known as primary martensite. The part of the austenite which does not transform to primary martensite during the cooling from the hardening temperature is called residual austenite. Hence the structure of as-hardened high speed steel consists essentially of undissolved complex carbide particles, primary martensite and residual austenite. This is true whether the steel has been heated up to the hardening temperature directly or with preheating at 1400–1600° F. and whether it has been cooled continuously or with an interruption at 1000° F.–1200° F.

The tempering of the hardened high speed steel involves heating it to approximately 950–1150° F. for a period ranging from a few minutes to about 12 hours, and then cooling in air to

room temperature. During this tempering operation the primary martensite present in the as-hardened steel is rapidly transformed into a somewhat softer product but this softening is counter-balanced by a secondary hardening caused by precipitation of hard complex carbide particles from the residual austenite and by the transformation of the residual austenite into hard martensite. The precipitation of complex carbides occurs principally at the tempering temperature while the transformation of residual austenite into hard martensite occurs principally during the cooling from the tempering temperature. Some austenite transformation may occur at the tempering temperature but the amount of this transformation is very small compared to that which occurs during the cooling from the tempering temperature. The martensite which is formed by transformation of residual austenite during the tempering or subsequent cooling is called secondary martensite and differs from the primary martensite referred to above in that the secondary martensite is more resistant to softening when heated. Ordinary tool steels do not undergo this secondary hardening during tempering because there is not enough residual austenite present in the as-hardened metal.

From the foregoing it will be seen that the as-tempered high speed steel consists essentially of complex carbides, both undissolved and precipitated, a somewhat softened product produced by the transformation of the primary martensite, and a hard product, produced by transformation of residual austenite, known as secondary martensite.

The foregoing explanation of the physical changes in high speed steel which occur during hardening and tempering as well as the following explanation of the changes brought about by my modified tempering treatment are based upon careful studies of the metal including measurements of density, magnetic properties, dilation, hardness, electrical conductivity, micro structure and X-ray examination. It is understood however that regardless of the correctness of these explanations the invention resides in the treatment applied to the steel and in the product obtained.

The transformation of the residual austenite during the cooling from the tempering temperature usually starts at a temperature below 600° F. and continues as the steel cools to room temperature. The transformation is accompanied by a marked relative increase in volume, that is to say the volume of the transforming material increases relative to the volume of the surrounding metal, and since this increase in volume occurs at low temperatures at which the

steel has little plasticity or ability to accommodate itself to non-homogeneous volume change, the result is the production of high internal stresses in the steel body. These stresses may result in distortion or even cracking of the hardened and tempered high speed steel articles during the cooling after tempering or while standing at room temperature after cooling or during the subsequent shaping or use of the articles. Cracking may mean the complete loss of the article while the distortion, if cracking does not occur, necessitates extra grinding of the article to attain the desired final size and shape. The internal stresses may also cause internal movements in the steel for some time after the final grinding and hence result in a troublesome change in shape or dimensions. Furthermore internal stresses are likely to lower the strength, toughness and ductility of the steel and thus cause premature failure of the article, e. g. the tool, during service.

Multiple tempering, i. e. tempering two or more times is employed in the art to some extent and has been reported to produce better tool life than single tempering. This improvement is due to the fact that the later tempering operations (after the first) partially relieve the stresses caused by the transformation of the residual austenite during the cooling stage of the initial tempering operation. However the stresses produced during the first cooling may have caused cracks or distortion, particularly in articles of complicated shape, and this damage cannot be repaired by subsequent tempering operations. It is therefore desirable to provide a tempering treatment which avoids or substantially reduces the stresses and distortion referred to.

Before preceeding with the description of my method I wish to make certain what I mean by the term high speed steels. High speed steels are a class of highly alloyed tool steels which, after suitable hardening and tempering, have the property of red hardness, that is, the ability to retain their hardness to a considerable degree at elevated temperatures. This is in contrast to ordinary tool steels which, regardless of their heat treatment, soften markedly at elevated temperatures. This means that tools made of ordinary steels must be operated at sufficiently low speeds to prevent generation of sufficient heat to raise them to a temperature at which they soften materially. High speed steel tools, on the other hand, may be operated at relatively high speeds because they remain relatively hard even at temperatures approaching dull red heat. The most common high speed steels contain 0.55-0.85% of carbon and are alloyed with tungsten, chromium and vanadium. Typical analyses are 18% tungsten, 4% chromium and 1% vanadium (called 18-4-1 high speed steel), 18% tungsten, 4% chromium and 2% vanadium (called 18-4-2 high speed steel) and 14% tungsten, 4% chromium and 2% vanadium (called 14-4-2 high speed steel). Another group or class of high speed steels contains molybdenum either in addition to or in place of tungsten. Type analyses are 1.5% tungsten, 4% chromium, 1% vanadium and 9% molybdenum (called molybdenum-tungsten high speed steel) and 4% chromium, 2% vanadium and 9% molybdenum (called molybdenum-vanadium high speed steel). 3 to 12% of cobalt may be added to any of the above steels to produce higher cutting efficiency. Another description of high speed steel is as fol-

lows. It is a steel containing chromium and vanadium and in addition tungsten and/or molybdenum. In general molybdenum may be substituted for tungsten, 1% of molybdenum being approximately equivalent to 2% tungsten. Thus there are three types or classes of high speed steel depending on whether they contain tungsten only or molybdenum only or both tungsten and molybdenum. There are other special classes of high speed steels which need not be described in detail but all of which are amenable to the method of heat treatment to be described below. That all high speed steels respond similarly to the heat treatment may be explained by the fact that in the hardened state they are all alike in that they consist essentially of hard carbides, primary martensite and residual austenite and all undergo the same or similar phase transformations. It will be understood that the base of all of the high speed steels is iron containing the usual elements such as manganese, sulfur, phosphorus, silicon, etc.

In accordance with the present invention the customary hardening and tempering operations described above are carried out as usual excepting that the cooling from the tempering temperature is interrupted for from a few minutes to as long as 48 hours at a temperature within the range from 200-700° F. As a result of this operation the residual austenite transforms isothermally into a denser, softer, tougher and more ductile product than the martensite formed during the usual practice of continuous cooling from the tempering temperature to room temperature. Because the isothermal transformation product is less voluminous and because it forms at a constant elevated temperature instead of during cooling, the internal stresses caused by the transformation of the residual austenite are less than when the steel is cooled in the usual way. Consequently the likelihood of distortion, cracking and premature failure in service are greatly reduced. Furthermore the softer, tougher and more ductile character of the isothermal transformation product improves the service life of tools which are subjected to repeated impact. This is an important consideration because many high speed steel tools fail by cracking or chipping in use rather than as a result of wear.

It is understood that the high speed steel, prior to the hardening and tempering treatments described above, is in a condition equivalent to that produced by the customary preliminary treatment which generally includes (1) casting the high speed steel from the liquid state into ingot molds (2) reheating the ingots to about 2000° F. and forging or rolling to break down the brittle cast structure and produce the desired shape, (the resulting forgings or rolled bars, after air cooling to room temperature, are too hard to be machined directly to final shape and hence are subjected to) (3) annealing by heating to about 1650° F. for several hours and slowly cooling and (4) machining the annealed objects into drills, cutters, saws, dies, etc. My invention is not limited with respect to the preliminary treatment of the high speed steel excepting that it is assumed that at the time of the application of the hardening treatment it is in the annealed state. As a matter of fact, since hardening is customary my invention resides in tempering with interrupted cooling as applied to a suitably hardened high speed steel or to a cast, forged or rolled, annealed and hardened high speed steel. My invention would of course be applicable if substan-

tially the same condition of the high speed steel as that produced by casting, working, annealing and hardening could be arrived at in some other way. For completeness it may be noted here that after the hardening and tempering the high speed steel articles produced customarily are subjected to a final grinding operation to final shape.

In the following description of the invention reference will be made to the accompanying drawings in which

Fig. 1 includes curves representing the continuous and interrupted cooling from the tempering temperature of a typical high speed steel,

Fig. 2 includes a series of curves showing the effect of interruption of the cooling at different temperatures, and

Fig. 3 is a curve showing the effect of time on the progress of the isothermal transformation of the residual austenite.

The optimum holding time and temperature for the interruption of the cooling from the tempering temperature depend upon a number of factors such as the composition of the high speed steel, the hardening temperature, the tempering temperature and the tempering time. As stated above the time may vary from a few minutes to 48 hours or longer and the temperature may be anywhere within the range from 200-700° F. but for practical operation a more precise determination of the time and temperature of the interruption is desirable. A valuable rule for the determination of the holding temperature in any particular instance is that it should be slightly below the temperature at which the residual austenite begins to transform during continuous cooling from the tempering temperature. This point readily may be determined by cooling hardened and tempered specimens of the high speed steel to be treated in a dilatometer so that the changes in length during the cooling can be measured. A plotting of the readings gives curves of which curve 1 in Fig. 1 of the accompanying drawings is typical. Referring to the drawings it is seen that curve 1, which represents the change in length of the sample during continuous cooling from the tempering temperature, coincides with curve 2, which represents the change in length of the sample during interrupted cooling and with curve 3, down to the holding temperature of 500° F. From this point downward the continuous cooling curve 1 bends leftward and ends at a point slightly above the end point of the interrupted cooling curve 2, that is to say the final length of the continuously cooled sample is greater than the final length of the sample which has been subjected to interrupted cooling, and the end points of both of curves 1 and 2 are materially above the end point of curve 3. The expansion due to residual austenite transformation therefore is greater in the case of the continuously cooled sample than in the case of the sample subjected to interrupted cooling. In other words, the volume or length of the continuously cooled sample differs from that of a theoretical product in which no austenite transformation occurs (curve 3) to a greater extent than the sample produced with interrupted cooling. The deviation of curve 1 from the straight line or regular curve 3 which would be expected if no change in the structure of the metal occurred during cooling is due to the transformation of residual austenite. Curve 2 shows that when the cooling of the sample is interrupted at 500° F. this transformation of residual austenite produces a sharp isothermal increase

in the length of the sample following which the cooling curve continues as a substantially straight line. This vertical portion of curve 2 starts at a point slightly below the temperature at which the residual austenite begins to transform.

The samples used in producing the curves of Fig. 1 were 18-4-1 high speed steel which had been hardened at 2350° F. and tempered at 1050° F. for 2½ hours. The interruption of the cooling of the sample for curve 2 was for 24 hours at 500° F.

Curve 3 is not purely theoretical but was determined experimentally by heating a specimen of hardened high speed steel rapidly to the tempering temperature and then, without any appreciable pause at the tempering temperature, cooling it immediately in a dilatometer. In this way the austenite was not conditioned for transformation and the specimen underwent substantially no transformation during the cooling. Hence the cooling curve showed the natural thermal contraction characteristics of the steel divorced from the effects of the austenite transformation.

Fig. 2 shows by curves 1 to 8 the effect of interrupting the cooling at different temperatures. Curve 1 is the continuous cooling curve and curves 2-8 inclusive show the interruption of the cooling at 200° F., 300° F., 400° F., 450° F., 500° F., 550° F., and 600° F. respectively. The interruption in each instance was for 24 hours. These curves show that the isothermal transformation of the residual austenite varies with the holding temperature and that the optimum temperature in this instance is at about 500° F. which, as is pointed out above, is slightly below the temperature at which the transformation begins during continuous cooling. If the cooling from the tempering temperature is stopped at a temperature above the optimum only a part of the residual austenite transforms isothermally and the remainder transforms during the subsequent cooling to room temperature. On the other hand if the cooling is interrupted at a temperature below the optimum, again only a part of the residual austenite transforms isothermally, the remainder having transformed during the cooling before the interruption. In either event the maximum effect of isothermal transformation is not obtained.

The samples used in the tests represented by the curves of Fig. 2 were 18-4-1 high speed steel hardened at 2350° F., and tempered at 1050° F. for 2½ hours.

As previously stated the optimum holding temperature depends principally upon the composition of the steel, the hardening temperature and the tempering temperature and time. The effect of hardening temperature, tempering temperature and tempering time is shown by the following data of tests carried out on samples of 18-4-1 high speed steel.

Effect of hardening temperature

Harden- ing temp.	Temper- ing temp.	Temper- ing time	Optimum isothermal transformation temp.
° F.	° F.	Hours	° F.
2,300	1,050	2½	510
2,350	1,050	2½	500
2,400	1,050	2½	450

Effect of tempering temperature

Harden- ing temp.	Temper- ing temp.	Temper- ing time	Optimum isothermal transforma- tion temp.
° F.	° F.	Hours	° F.
2,350	1,000	2½	250
2,350	1,050	2½	500

Effect of tempering time

Harden- ing temp.	Temper- ing temp.	Temper- ing time	Optimum isothermal transforma- tion temp.
° F.	° F.	Hours	° F.
2,350	1,050	1	375
2,350	1,050	2½	500
2,350	1,050	5	530

From these data it appears that for a given high speed steel composition the optimum isothermal transformation temperature is higher the lower is the hardening temperature and conversely. The optimum isothermal transformation temperature is also higher with higher tempering time and conversely.

As appears from Fig. 3 of the drawings, which shows the isothermal expansion as a function of time due to isothermal transformation of residual austenite at 500° F. on samples of 18-4-1 high speed steel hardened at 2350° F., and tempered at 1050° F. for 2½ hours, the isothermal transformation is practically complete at the optimum temperature in 24 hours. However for some classes of high speed steel 36-48 hours may be required for substantially complete isothermal transformation at the optimum holding temperature. It is noted that the transformation is about 50% complete in 1 hour in the case of 18-4-1 high speed steel.

Numerous tests such as those described above enable me to define the holding temperature more closely as lying within the range from 300-640° F. and still more closely as lying within the range 400-600° F. A temperature of 500° F. may be said to be the average optimum holding temperature.

It may be observed from the above disclosures that the isothermal transformation of the residual austenite in hardened and tempered high speed steel, at an elevated temperature at or near the optimum, results in lower internal stresses than when the residual austenite transforms during continuous cooling over a range of temperature substantially below the optimum isothermal transformation temperature. Moreover the isothermal transformation product is different from the secondary martensite which forms during continuous cooling from the tempering temperature. The isothermal transformation product is both softer and less voluminous than the secondary martensite. For example, after hardening at 2350° F. and tempering for 2½ hours at 1050° F. followed by the usual air cooling to room temperature, samples of 18-4-1 high speed steel showed a hardness of 65-65.5 Rockwell C units whereas identical samples treated in exactly the same way excepting that the cooling from the tempering temperature was interrupted at 500° F. for 20 hours showed a hardness of 63-64 Rock-

well C units. It may be explained that lower Rockwell C unit values indicate greater ductility and toughness. The slightly reduced hardness which accompanies the increased ductility and toughness is not important excepting in certain very special uses.

The formation of the less voluminous isothermal transformation product reduces, as compared with the volume of the product produced by continuous cooling, the extent of volume change associated with the transformation of the residual austenite and hence results in less internal stress and closer control of the shape and dimensions of the high speed steel articles. Moreover the softer isothermal transformation product is accompanied by greater ductility and toughness than the product obtained by continuous cooling.

The rate of continuous cooling down to the isothermal transformation point and from that point to room temperature appear to be without substantial effect. However as will be apparent from a consideration of curves 2 to 8 of Fig. 2 any prolonged interruption of the cooling within the range of isothermal transformation, i. e. within the range from about 200° F. to about 700° F. will have a beneficial effect. It is apparent also from a consideration of these curves that the desired results may be obtained by interruption of the cooling for a sufficient period of time at a single selected temperature or by interrupting the cooling for shorter periods at more than one selected temperatures within the transformation temperature range. It will be appreciated that in practical operation and in the tests described above isothermal transformation of residual austenite is not entirely complete but is sufficient for all practical purposes.

The tempered steel may be cooled in the tempering furnace to the holding temperature, held at this point for the desired length of time and then cooled in the air to room temperature. Or the tempered steel may be transferred from the tempering furnace to another furnace or a liquid bath operating at the desired holding temperature, held at this temperature for the desired length of time and then cooled to room temperature. A variety of ways of handling the tempered steel to accomplish the desired holding at the selected isothermal transformation temperature will be apparent on consideration. It is of course not necessary to design the treatment for a complete transformation of the residual austenite. Beneficial effects may be obtained, as is indicated by the curve of Fig. 3, in periods of time which amount to only a small fraction of that required for substantially complete transformation.

The results obtained by interrupting the cooling from the tempering temperature are not, so far as I am aware, obtainable in any other way. Neither interrupted cooling from the hardening temperature nor tempering at the holding temperature will give the desired transformation in any reasonable length of time. This apparently is because the residual austenite must be conditioned for the transformation by the tempering treatment, i. e. by holding the hardened metal at a tempering temperature of 950-1150° F. for a substantial period. Even when a high speed steel which has been hardened and tempered as usual is reheated to the tempering temperature a second time and then cooled with an interruption within the transformation range the results are not the same as when the interruption occurs during the cooling which immediately fol-

lows the first tempering because the residual austenite transforms during the continuous cooling following the first tempering into secondary martensite which causes the high internal stresses and which is not softened appreciably by the reheating operation.

Further for completeness it is noted that further heat treatment of the high speed steel following the interrupted cooling from the tempering temperature is not precluded. For instance it may be advantageous in some instances to relieve stresses in the article by a second tempering. The reheating of the article to the second tempering temperature may directly follow the step of holding the article at the isothermal transformation temperature (without cooling to room temperature after the holding treatment) or the article may be cooled to room temperature after the holding treatment and then reheated to the second tempering temperature. The second tempering may be at say 750° F. to 1200° F. for say 15 minutes or more followed by continuous cooling to room temperature. More particularly the second tempering operation should be at about 1000° F. for two hours or at about 1050° F. for one hour. If the second tempering is carried out at a temperature above 1150° F. the softening of the high speed steel is so rapid that it is difficult to control the time of heating so as to avoid excessive softening.

It will be observed that in the foregoing description the data of the specific examples and the data for the curves of the drawings were obtained from tests upon 18-4-1 high speed steel. I have however carefully pointed out that the principles of the invention illustrated are applicable to high speed steels generally. The invention embraces all known or obvious variations in the hardening and tempering procedures and conditions so long as the cooling of the metal, after hardening and tempering, from the tempering temperature is interrupted for a substantial period of time within the range of residual austenite transformation.

The following data on the mechanical properties of 18-4-1 high speed steel after the customary heat treatment and after heat treatment in accordance with the invention will serve to illustrate the improvement produced by the latter:

Steel..... 18-4-1
Hardening treatment..... Oil quenched from 2350° F.
Tempering treatment..... 2½ hours at 1050° F. and cooled as follows:

Properties	Cooled in air to room temperature (usual practice)	Cooling held at 400° F. for 20 hours
Rockwell C hardness.....	65	64
Modulus of rupture in bending pounds per square inch.....	408,000	450,000
Maximum permanent set before breaking in bending percent.....	0.07	0.15
Modulus of rupture in torsion pounds per square inch.....	310,000	346,000
Angle of twist before breaking in torsion degrees.....	80	115
Torsion impact strength..... foot-pounds.....	48	109

Observations:

The hardness values of tool steels are usually

expressed in Rockwell C units. The table shows that the interrupted cooling treatment results in a slightly softer steel than does the usual treatment.

The tensile strength of hardened tool steels cannot be determined by the standard tensile test because of the relative brittleness of the steels. The modulus of rupture in bending may be taken as a measure of the tensile strength. The interrupted cooling treatment improves this property by approximately 10%.

The extent of maximum permanent set produced in a bend test may be considered as an index of ductility in tension. The interrupted cooling treatment improves this property by about 100%.

The modulus of rupture in torsion may be taken as a measure of shear strength. The interrupted cooling treatment results in about a 10% improvement in this property.

The angle of twist before breaking in torsion may be regarded as an index of ductility in shear or torsion. The interrupted cooling treatment produces approximately 45% improvement in this property.

The torsion impact strength indicates the ability of a steel to withstand shock or suddenly applied stresses without breaking. The interrupted cooling treatment causes about a 120% improvement in this property.

I claim:

1. Process for the heat treatment of high speed steel which comprises hardening and tempering the steel and interrupting the cooling of the steel from the tempering temperature at a temperature within the range from 700° F. to 200° F.

2. Process for the heat treatment of high speed steel which comprises hardening and tempering the steel and interrupting the cooling of the steel from the tempering temperature at a temperature within the range from 640° F. to 300° F.

3. Process for the heat treatment of high speed steel which comprises hardening and tempering the steel and interrupting the cooling of the steel from the tempering temperature at a temperature within the range from 600° F. to 400° F.

4. Process for the heat treatment of high speed steel which comprises hardening and tempering the steel and interrupting the cooling of the steel from the tempering temperature at a temperature of about 500° F.

5. Process as defined in claim 1 in which the interruption of the cooling is for a period of at least ½ hour.

6. Process as defined in claim 1 in which the interruption of the cooling is for a period of from ½ to 48 hours.

7. Process as defined in claim 1 in which the interruption of the cooling is at a temperature slightly below that at which residual austenite begins to transform during continuous cooling.

8. Process for the heat treatment of high speed steel which comprises hardening the steel by heating it to a temperature of from 2100° F. to 2400° F., and cooling the steel to room temperature, tempering the hardened steel by heating it to a temperature of from 950° F. to 1150° F. for a period from a few minutes to 12 hours, cooling the steel to a temperature within the range from 700° F. to 200° F., interrupting the cooling at said temperature, and finally cooling the steel to room temperature.

9. Process of heat treating high speed steel which comprises interrupting the cooling of the hardened and tempered steel from the tempering

temperature at a temperature within the range from about 700° F. to about 200° F., holding the steel at said temperature until a substantial portion of the total possible expansion at said temperature has occurred and finally cooling the steel to room temperature. 5

10. Process as defined in claim 9 in which the cooling of the steel is interrupted at a plurality of temperatures within said range.

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