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[54] **HOT FORGING PROCESS**

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[51] **Int. Cl.** **B21j 1/06**
[58] **Field of Search** 148/12; 72/364

[56] **References Cited**

UNITED STATES PATENTS

3,001,897	9/1961	Nachtman	148/12
3,488,231	1/1970	Zackay et al.	148/12
3,619,302	11/1971	Aoki et al.	148/12
3,645,801	2/1972	Melloy et al.	148/12
3,673,007	6/1972	Miyano et al.	148/12

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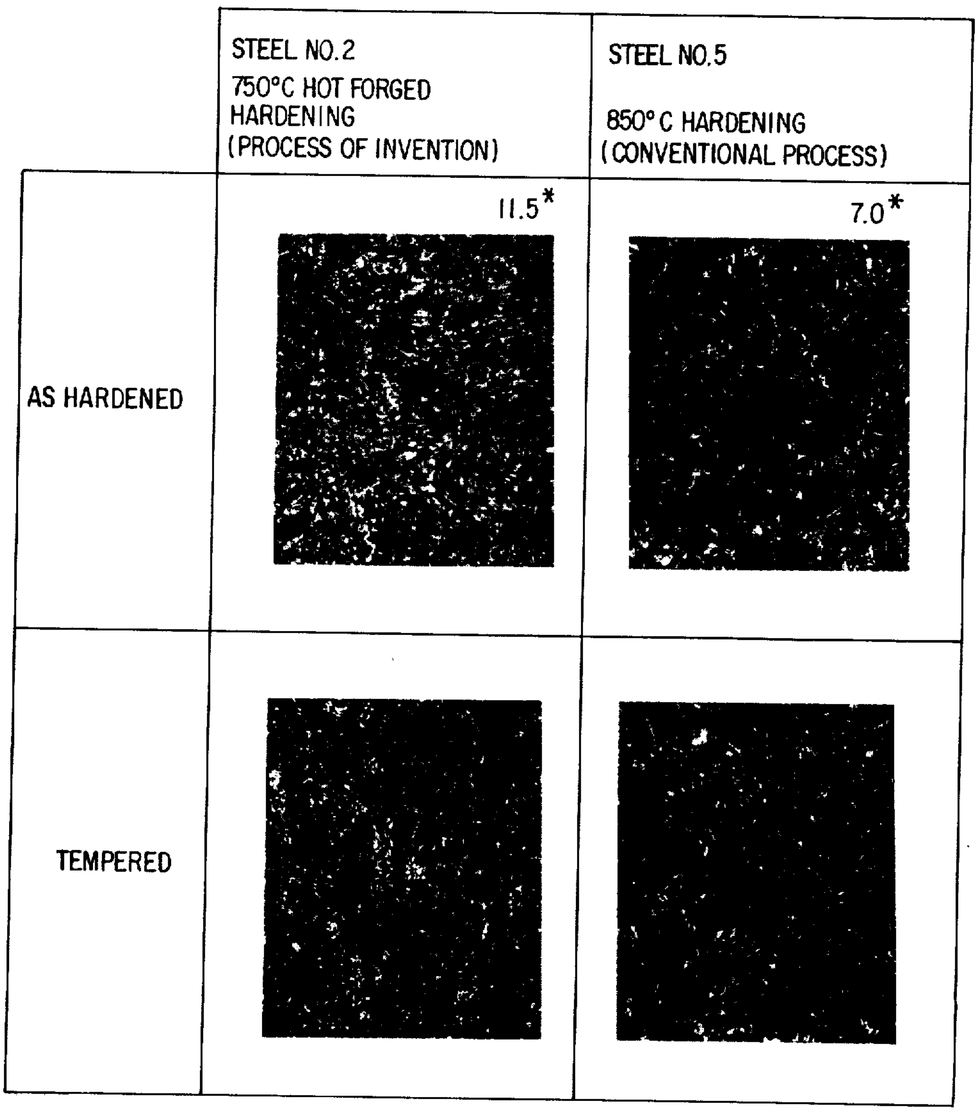
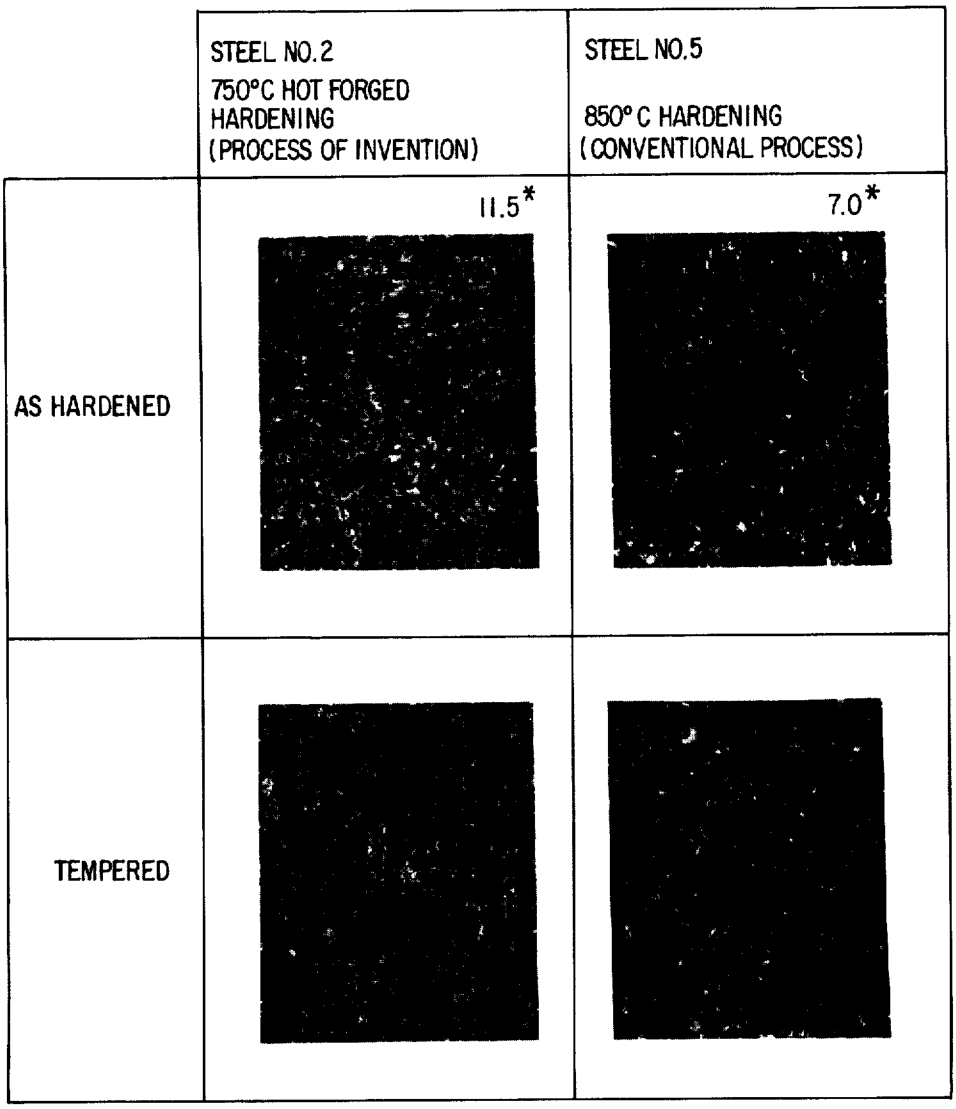
[57] **ABSTRACT**

A hot forging process for steels which comprises pretreating a steel, such as by heat treatment or plastic working, and then hot forging the treated or worked steel at a temperature in the range from 450°C to the A_{c1} transformation point of the steel. This procedure obviates the use of subsequent heat treatments of the steel after the hot forging.

5 Claims, 2 Drawing Figures



* HEAT TREATMENT GRAIN SIZE



* HEAT TREATMENT GRAIN SIZE

FIG. 1

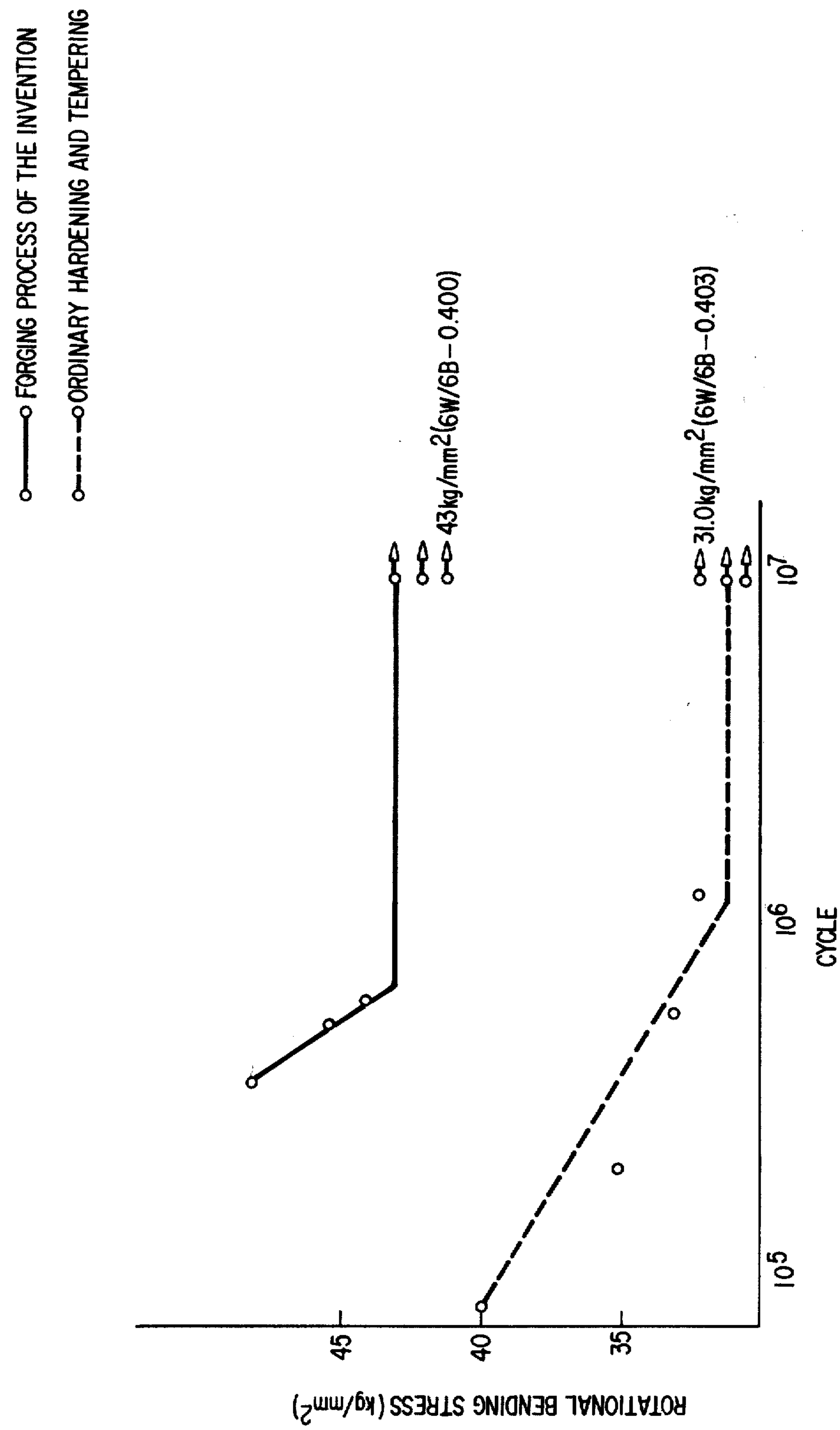

FORGING PROCESS OF THE INVENTION
ORDINARY HARDENING AND TEMPERING
43kg/mm2(6W/6B-0.400)
31.0kg/mm2(6W/6B-0.403)
ROTATIONAL BENDING STRESS (kg/mm2)
45
40
35
10^5
10^6
10^7
CYCLE

FIG. 2

HOT FORGING PROCESS

BACKGROUND OF THE INVENTION

1. Field of the Invention:

This invention relates to a hot forging process at a temperature in the range of **450°C** to the A_{c1} transformation point. More particularly, the present invention relates to a preparatory treatment of steel which is a heat treatment or plastic working of the steel before a final hot forging step to achieve forgings or forged products having improved mechanical properties and an attractive appearance with a minimum formation of scale on the surface of the forgings.

2. Description of the Prior Art:

Generally, conventional hot forging at temperatures ranging from 450°C to the A_{c1} transformation point is intended to forge materials to achieve a non-symmetrical configuration which otherwise could not be obtained by cold forging techniques on materials which dictate a high degree of workability or on materials to which cold forging is not applicable. However, the conventional hot forging techniques suffer from the disadvantages in that heat treatments are required after forging to achieve the desired mechanical properties in the forged products. This heat treatment results in the warping of or in the introduction of residual strain into the forged products and/or results in the impairment of the dimensional accuracy and the surface appearance of the forged products.

Prior art procedures which have been developed to improve the toughness or mechanical properties of forgings include hot working utilizing a thermo-mechanical treatment, forged hardening, ausforming, ausrollingtempering and the like. Among these techniques, forged hardening and ausforming are quite well known. However, these thermo-mechanical treatments include the steps of heating a material to an austenite zone above the A_{c3} transformation point and then working the metal while it is cooled. These procedures not only require the use of complicated forging or working techniques, but also require critical control of timing or temperature, and the like. However, these techniques still result in products whose surfaces are covered with scales, because these techniques require the use of an elevated temperature in the austenite zone above the A_{c3} transformation point.

A need, therefore, continues to exist for a process of hot forging carbon steels or low alloy steels at temperatures ranging from 450°C to the A_{c1} transformation point, which obviates a heat treatment step after the final forging of the steel and which presents a simple but effective means for improving the mechanical properties of the forged products.

SUMMARY OF THE INVENTION

Accordingly, one object of the invention is to provide a hot forging process at a temperature of 450°C to the A_{c1} transformation point, which process obviates the use of a heat treatment step after the final forging, yet which results in a forged product having improved mechanical properties.

Another object of the invention is to provide a hot forging process which employs several types of preparatory treatments before the final hot forging step, so as to eliminate a subsequent heat treatment step thereafter which must be used in conventional forging processes.

Briefly, these objects and other objects of the invention as hereinafter will become more readily apparent can be attained by a hot forging process which comprises heat treating or plastic working a steel and then hot forging said heat treated or plastic worked steel at a temperature in the range from 450°C to the A_{c1} transformation point. This method of treatment obviates the need for heat treatment steps after the hot forging step.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete appreciation of the invention and many of the attendant advantages thereof will be readily obtained as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings, wherein:

FIG. 1 is a series of photomicrographs of the structures as hardened and tempered plus the heat treatment grain size of AISI 1045 steels which have been subjected to forged hardening → hot hot forging and normal hardening → tempering; and

FIG. 2 is a plot showing the results of ONO-type rotational bending fatigue tests of rolled AISI 1045 steels which have been subjected to hardening → hot forging and ordinary hardening → tempering.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the first aspect of the invention, a hot forging process is provided which includes an initial pretreatment step of heat treating or of plastic working a carbon steel or a low alloy steel and then forging the same at a temperature in the range of 450°C to the A_{c1} transformation point, thereby improving the mechanical properties of the forged steel. The combined treatments produce a steel free from warping or residual strain unlike steels which are subjected to the conventional heat treatment, which do not have inaccurate dimensions and undesirable surface roughness.

In the second and third aspects of the invention, a hot forging process of the type described is provided, in which, before the final hot forging, the starting steel is heat treated or hardened and tempered.

In the fourth and fifth aspects of the invention, a hot forging process of the type described is provided in which, before the final hot forging, the starting steels as rolled or normalized are heated to a temperature in the ferrite + austenite zone below the A_{c3} transformation point, and the final forging is applied at the aforesaid temperature. In this respect, the temperature of the steel is raised because of the forging heat up to a temperature close to the A_{c3} transformation point or above. When the steels have been subjected to this forging treatment, the austenite formed before forging and the austenite which has been formed because of the temperature increase from the forging heat will cause deformation of the steel thereby giving a structure which contains relatively fine grains of austenite. When steels thus forged are quenched, steels having a hardened, finer martensite structure are obtained. If required, hardening and tempering treatments may be applied to the steels before the final hot forging.

The starting temperature of the steels in this preparatory hot forging treatment before the final hot forging should be high enough to austenitize the steels because of the forging heat. For this reason, the temperature of the steels to be heated should be maintained above the A_{c1} transformation point of the steels. However, when the forging rate or the working rate in the preparatory treatment stage is relatively small, a lesser degree of austenitization of the steels caused by the forging heat occurs which means that the steel produced will not have the desired toughness and strength even if the steel is heat treated after forging. For this reason, the temperature of the steels, which steels have two austenite and ferrite phases, heated in the preparatory forging step should range between the A_{c1} transformation point and the A_{c3} transformation point and preferably in the range between the A_{c3} transformation point and 50°C less than the A_{c3} transformation point. On the other hand, when the steel is heated above the A_{c3} transformation point in the preparatory forging, the temperature of the steels will be increased too high to obtain a fine structure, resulting in no improvement in the toughness of the steels.

The steels which have been subjected to the preparatory forging treatment are subsequently subjected to quench-hardening to give a fine martensite structure. Of course, unless the steels have completely been austenitized in the preparatory forging step, there is no harm with steels which partly contain a ferrite structure. The steels thus hardened are finally tempered and normalized to give the desired strength and toughness. The hardening step after the preparatory forging may be an oil quenching procedure. However, if the steel products are small, then air cooling may be used in the quenching step.

After the preparatory forging and heat treatment steps, the final hot forging treatment is applied to the steels.

In the sixth aspect of the invention, a hot forging process of the type described is provided, in which, before the final hot forging at a temperature from 450°C to the A_{c1} transformation point, a cold working step such as cold drawing, cold rolling or the like is applied to the steels at a reduction-of-area percentage of at least 15%. The cold working step imparts working strain into the steels.

The reduction-of-area percentage in the cold working step as used herein should be over 15% to obtain the desired toughness for forgings after the final hot forging. If lesser degrees of reduction-of-area percentage are obtained, such as for instance by only several percentage points, such as used in the cold or hot heading process for bolts, the desired improved mechanical properties may not be obtained.

The steels which have been subjected to cold working are finally hotforged at a temperature ranging from 450°C to the A_{c1} transformation point. If the forging temperature is lower than 450°C, i.e., in the blue shortness range, then the working resistance (working load) will be increased which results in difficulties when the steels are worked. On the other hand, if the forging temperature exceeds the A_{c1} transformation point, then a too high forging temperature will result, thereby neutralizing the effect of the working strain imparted by the cold working step. Thus, the forgings produced do not have improved toughness. Forgings having better mechanical properties are obtained at greater heating rates and, therefore, shorter heating times in the forging of the steel in the above temperature range. The heating rate should preferably be at least 30°C/min, and the time period over which the forging is heated should be less than 40 minutes. In addition, the slower the cooling rate, the greater the strength of the product forging. However, at relatively greater cooling rates, forgings are produced having greater toughness. For these reasons, the extrusion speed when the forging is extruded is preferably over 5 mm/sec. The cooling rate after the final hot forging, however, should be as great as possible to obtain the desired improved strength. However, forgings with greater toughness may be obtained at lower cooling rates. Thus, the aforesaid factors must be evaluated and determined depending on the requirements necessary for the product forgings.

In the seventh and eighth aspects of the invention, a hot forging process of the type described is provided, in which, before the final hot forging at a temperature of from 450°C to the A_{c1} transformation point, the steels are heated to a temperature above the A_{c3} transformation point in the hot forging process. Thereafter, the forging is hardened and then heated again to a temperature in the range from 450°C to the A_{c1} transformation point for the final hot forging. The hot forging process is followed by air cooling or cooling at a rate greater than the air cooling. These steps are preparatory treatments before the final hot forging treatment at a temperature of from 450°C to the A_{c1} transformation point. In the preparatory hot forging steps, the steels are heated to a temperature above the A_{c3} transformation point. In this case, however, the scale formed on the surface of the forgings may be readily removed by the forged hardening treatment.

The final forging temperature of 450°C to the A_{c1} transformation point is relatively low and this results in considerably improved dimensional accuracy and surface appearance of the steel. Also, the cooling rate as used herein apparently depends on the configuration and dimensions of the steels to be forged, and hence the cooling rate can not be specified herein. However, the cooling rate should be such that the steels have a martensite structure after hot forging at a temperature over the A_{c3} transformation point.

Forged steels having improved strength and toughness are obtained by the hot forging process of the invention in comparison to those steels which have been forged by the conventional hardening, tempering and normalizing treatments. The heat treatment and working of the steel before the final hot forging particularly contributes to the greatly improved mechanical properties of the steel. Further, steels treated by the process of the present invention have improved toughness, compared with steels having a ferrite or perlite structure and which have been subjected to hot forging in an as rolled condition.

In the final step of the process of the invention, a hot forging step at a temperature from 450°C to the A_{c1} transformation point is provided which obviates the necessity of a normalizing treatment which is required in conventional cold forging techniques. The process of the present invention greatly improves the appearance of forged products as well as the strain caused by the heat treatment, thereby giving a steel product with improved, consistent dimensional accuracy.

Furthermore, by the process of the present invention, a tempering treatment may be simultaneously applied during the hot forging operation, thus dispensing with a separate tempering treatment which offers a considerable advantage in the production of forgings. However, if problems concerning the equipment for tempering or hardening treatments are of little consequence, steels which have been subjected to hardening and tempering may again be heated to the desired temperature selected for the final hot forging.

Table I shows the chemical composition of the samples used on a weight percent basis of the forgings of the invention.

TABLE I

Type of Steel	C	Si	Mn	P	S	Cu	Ni	Cr	Mo
AISI 1045	0.47	0.22	0.79	0.011	0.012	0.01	0.02	0.11	
AISI 4118	0.20	0.30	0.75	0.016	0.008	0.04	0.04	1.06	0.20

Table II illustrates the comparison of the mechanical properties of two types of AISI 1045 steel bars 25 mm in diameter. One type of such bars has been subjected to a heat treatment or plastic working and then hot forged at a temperature ranging from 450°C to the A_{c1} transformation point and the other sample has been subjected to only a heat treatment or plastic working.

TABLE II

Results of Hot Forging								
Type of steel	Condition of samples	Treatment	Yield point (kg/mm^2)	Tensile strength (kg/mm^2)	Elongation $4\cdot\sqrt{A}$ (%)	Reduction-of-area % (%)	Impact value $(kg\text{-}m/cm^2)$
AISI 1045	Hardening	850°C hardening, 600°C tempering	61.0	76.9	28.0	61.5	11.6
		850°C hardening → 600°C hot forging	58.5	75.4	26.9	65.3	15.8
		850°C hardening 600°C tempering → 600°C hot forging	67.5	80.0	28.1	67.9	20.3
	Hot forging	850°C forged hardening 600°C tempering	67.4	77.9	23.2	62.6	16.5
		850°C forged hardening → 600°C hot forging	67.3	79.2	27.7	64.2	19.5
		750°C forged hardening → 600°C hot forging	67.5	80.0	23.2	60.5	22.5
	Cold working	as rolled	55.0	74.2	24.3	44.5	4.4
		After rolling, 20% cold working → 600°C hot forging	85.1	99.8	16.3	46.4	10.5

The impact values of the steel are materially improved by the hot forging treatment at 600°C. When the steels are hot forged at 600°C, along with the varying treatments prior to the hot forging, forged steels are obtained which have excellent mechanical properties without the application of a heat treatment after the final hot forging.

Various preliminary treatments of steels before the hot forging will now be described.

Table III shows the mechanical properties of steel samples 25 mm in diameter shown in Table I, which samples have been subjected to rolling (as rolled), a heat treatment or hardening and tempering. Thereafter, the steel samples were subjected to hot extrusion - forging at a temperature of 450°C to the A_{c1} transformation point at a working speed of 20 mm/sec until a diameter of 16 mm was reached. The forged steel samples were then quenched in water. This procedure was followed in the second and third aspects of the invention.

TABLE III

Mechanical Properties of Hot Extrusion-Forged Steels						
Type of steel	Treatment	Yield point (kg/mm^2)	Tensile strength (kg/mm^2)	Elongation $4\sqrt{A}$ (%)	Reduction-of-area % (%)	Impact value $(kg\text{-}m/cm^2)$
AISI 1045	Hardening → tempering	47.1	76.9	27.4	64.3	9.4
	Hardening → hot forging	93.7	107.4	17.0	55.1	12.7
	Hardening and tempering → hot forging	89.5	101.0	18.2	58.5	13.3
	As rolled → hot forging	95.0	105.4	13.0	35.6	6.0

TABLE III – Continued

Mechanical Properties of Hot Extrusion-Forged Steels

Type of steel	Treatment	Yield point (kg/mm²)	Tensile strength (kg/mm²)	Elongation $4\sqrt{A}$ (%)	Reduction-of-area % (%)	Impact value (kg-m/cm²)
AISI 4120	Hardening → tempering	63.0	73.6	25.6	71.8	18.5
	Hardening → hot forging	101.9	103.9	19.8	61.2	20.9
	Hardening and tempering → hot forging	95.2	98.5	20.6	64.8	22.5
	As rolled → hot forging	82.8	95.8	15.9	51.2	13.8

The hardening and tempering conditions are as follows:
AISI 1045 850°C × 30 min. OQ→600°C × 30 min.
AISI 4120 880°C × 30 min. OQ→600°C × 30 min.
Hardening→hot forging: After hardening, the steel samples are heated at 600°C for 30 minutes and then hot extrusion-forged.
Hardening tempering→hot forging: After hardening, the steel samples are tempered, heated at 600°C for 30 minutes and then hot extrusion-forged.
As rolled →hot forging: The rolled steels are heated at 600°C for 30 minutes and then hot extrusion-forged.

The forgings which have been subjected to hardening (tempering) and hot forging exhibit elongation and reduction-of-area percentage values somewhat lower than those samples which have been subjected to a hardening and tempering treatment. In addition, they also exhibit greater tensile strength, yield points and impact values than the unforged samples. Forgings which have been subjected to hardening and then hot forging by the process of the present invention have materially improved ductility and toughness compared to those forgings which have been subjected to rolling and hot forging.

FIG. 2 shows the results of 'ONO' type rotational bending fatigue tests on steels which have been subjected to hardening and hot forging by the process of the invention as well as steels which have been subjected to conventional hardening and tempering treatments. As can be seen from FIG. 2, the forgings of the present invention have a superb fatigue strength 12 kg/mm² greater than the values of the forgings which have only been subjected to hardening and tempering.

Table IV shows the mechanical properties of AISI 1045 steel bars 25 mm in diameter which have been subjected to hot forging under the same conditions as has been previously described in which the steels have been hot forged with a ½ ton hammer at 60 cycles/min. By this free forging technique, round bars are obtained which have a diameter of 16 mm.

TABLE IV

Mechanical Properties of Hot-Forged Steels

Type of steel	Treatment	Yield point (kg/mm²)	Tensile strength (kg/mm²)	Elongation $4\sqrt{A}$ (%)	Reduction-of-area % (%)	Impact value (kg-m/cm²)
AISI 1045	Hardening → tempering	47.1	76.9	27.4	64.8	9.4
	Hardening → hot forging	70.0	85.4	25.8	63.5	13.3

As is clear from Table IV, steels which have been subjected to free forging also exhibit improved toughness and strength as in the case of extrusion-forged steels.

In the fourth and fifth aspects of the invention, AISI 1045 sample steels of 25 mm diameter were placed in a heating furnace maintained at 820°C (A_3 + 27°C), 780°C (A_3 − 13°C), and 750°C (A_3 − 43°C), respectively, for 30 minutes and then each sample was free forged to a 20 mm diameter. Thereafter, the samples were immediately forged and water quenched. Subsequently the steels thus treated were heated to 600°C for 30 minutes and then subjected to hot forging until a diameter of 16 mm was reached. The mechanical properties obtained for the forged steels are shown in Table V.

As can be seen from Table V, the steel forgings obtained by the process of the present invention have a strength and toughness greater than the steels which have been subjected to conventional hardening and tempering treatments. In particular the impact values are twice as great as those steels treated by the conventional process. The improved properties of the steels obtained from the process of the present invention stem from the finer grain structure of the steels. FIG. 1 is a series of several photomicrographs which show the grain sizes (heat treatment grain size) of a No. 2 steel obtained by the present invention and a No. 5 steel obtained by the conventional process. The data in Table V is indicative of the fine grain size (heat treatment grain size) of steel No. 2.

TABLE V

No.	Type of steel	Treatment	Mechanical Properties. Yield point (kg/mm^2)	Tensile strength (kg/mm^2)	Elongation $4\sqrt{A}$ (%)	Reduction-of-area % (%)	Impact value (kg-m/cm^2)
1	AISI 1045	820°C forged hardening → 600°C hot forging	69.0	83.6	24.1	60.4	15.0
2		750°C forged hardening → 600°C hot forging	67.5	80.0	23.2	60.5	22.5
3		730°C forged hardening → 600°C hot forging	68.0	83.5	25.2	62.0	26.0
4		730°C forged hardening → 600°C tempering 600°C hot forging	68.5	84.0	26.0	64.3	27.0
5		850°C hardening → 600°C tempering	61.0	76.9	28.0	61.5	11.6

In the sixth aspect of the invention, AISI 4120 rolled steels were machined to diameters of 22, 23.2 and 24.6 mm respectively. Thereafter the rolled steels were cold worked at rates of 0, 10 and 20%, respectively. The steels thus prepared were then placed in a heating furnace for 17 minutes, followed by hot extrusion-forging to a diameter of 16 mm (60% reduction-of-area percentage) at a working speed of 20 mm/sec.

As shown in Table VI, the steels which have not been cold worked have their strength and toughness improved by means of the hot forging. However, steels which have been subjected to 20% cold working have improved toughness, particularly medium carbon steels. On the other hand, the forging temperature of 730°C which is higher than the A_{c1} transformation point neutralizes the effect of cold working, with the resulting lowered strength.

TABLE VI

Effects of Cold Working Rate and Forging Temperature

Type of steel	Forging temperature (°C)	Cold working rate (%)	Yield point (kg/mm^2)	Tensile strength (kg/mm^2)	Elongation $4\sqrt{A}$ (%)	Reduction-of-area % (%)	Impact value (kg-m/cm^2)
AISI 1045	not forged	0	55.0	74.2	24.3	44.5	4.4
		10	74.8	84.5	16.5	40.5	3.2
		20	81.1	90.2	11.7	37.0	2.6
	600°C	0	84.4	98.3	15.7	43.2	6.5
		10	85.0	98.8	15.9	44.0	7.0
		20	85.1	99.8	16.3	46.4	10.5
	730°C	0	69.7	87.4	20.7	51.4	10.1
		10	70.5	88.2	20.8	51.5	11.0
		20	71.5	88.4	20.9	52.3	12.8
AISI 4120	not forged	0	46.5	66.5	26.2	51.5	6.0
		20	75.5	85.0	11.5	39.2	3.3
	600°C	0	82.8	95.8	15.2	50.2	12.8
		20	87.9	99.4	15.9	52.8	13.8

Table VII shows the effects of 17 and 34 minute holding times on hot forging, at a temperature of 600°C. As shown in Table VII, the holding time at the hot forging temperature has little or no effect on steels which have not been cold worked. However, when steels are cold worked, the shorter the holding time, the greater the toughness (impact value).

TABLE VII

Effects of Holding Time at a Heating Temperature of 600°C

Type of steel	Cold working rate(%)	Holding time at a heating temperature (Min.)	Yield point (kg/mm2)	Tensile strength (kg/mm2)	Elongation $4\sqrt{A}$ (%)	Reduction-of-area % (%)	Impact value (kg-m/cm2)
AISI 1045	0	17	84.4	98.8	15.7	43.2	6.5
		34	84.6	98.7	15.1	42.2	6.2
	20	17	85.1	99.8	16.3	46.4	10.5
		34	85.6	98.6	15.8	44.7	9.7

Table VIII shows the mechanical properties of steels which have been heated in a heating furnace at 600°C, and then subjected to 60% hot extrusionforging to a reduced diameter of 14 mm at working speeds of 20 mm/sec and 200 mm/sec followed by water quenching.

TABLE VIII

Effects of Working Speed							
Type of steel	Cold working rate (%)	Working speed (mm/sec.)	Yield point (kg/mm2)	Tensile strength (kg/mm2)	Elongation $4\sqrt{A}$ (%)	Reduction-of-area (%)	Impact value (kg-m/cm²)
AISI 1045	0	20	84.4	98.3	15.7	43.2	6.5
		200	84.5	98.5	15.6	45.6	6.7
	20	20	85.1	99.8	16.3	46.4	10.5
		200	85.8	100.0	16.7	50.1	14.2

As is apparent from the data of Table VIII, the higher the working speed, the greater the impact value. This tendency however is even more evident in those steels which have been subjected to cold working.

Table IX shows the data obtained by water cooling and slow cooling steel samples after hot forging. The data further shows the mechanical properties of steels which have been subjected to 20% cold working, heated for 17 minutes in a heating furnace maintained at 600°C and then subjected to hot forging to a reduced diameter of 14 mm (60% working) at a working speed of 20 mm/sec followed by water quenching.

TABLE IX

Effects of Cooling Conditions							
Type of steel	Cold working (%)	Cooling condition	Yield point (kg/mm2)	Tensile strength (kg/mm2)	Elongation $4\sqrt{A}$ (%)	Reduction-of-area percentage (%)	Impact value (kg-m/cm2)
AISI 1045	20	Water quenching	85.1	99.8	16.5	46.4	10.5
		Slow cooling	64.3	80.2	23.1	53.9	12.2

As can be seen from Table IX, when the hot forged steel is cooled at the higher rate, the greater is the strength and the lower the ductility. At the lower cooling rate, the steel has a lower strength and a greater ductility. However, in either case, greater thoughness (impact value) of the steel can be achieved by resorting to the process of the invention.

In the seventh and eighth aspects of the invention, rolled bars of AISI 1045 steel with a diameter of 25 mm were forged hardened at a temperature above the A_{c3} transformation point and then hot forged. The results of the tests are shown in Table X.

TABLE X

		Mechanical Properties				
Type of steel	Treatment	Yield point (kg/mm2)	Tensile strength (kg/mm2)	Elongation $4\sqrt{A}$ (%)	Reduction-of-area percentage (%)	Impact value (kg-m/cm2)
AISI 1045	850°C forged hardening → 600°C hot forging	67.3	79.2	27.7	64.2	19.5
	850°C forged hardening, 600°C tempering → 600°C hot forging	67.5	80.0	28.1	67.9	20.3
	850°C forged hardening → 600°C tempering	67.4	77.9	23.9	62.6	16.5
	850°C hardening → 600°C hot forging	58.5	75.4	26.9	65.3	15.8
	850°C hardening → 600°C tempering	61.0	76.9	28.0	61.5	11.6

Table X proves that forgings obtained by the process of the invention can retain the same level of strength as those steels which have been subjected to forged hardening while having improved impact values. The step of forged hardening prior to the hot forging step improves the strength and impact value to a substantial degree. The hot forging process of the invention produces excellently forged steels which can not be achieved by the conventional hardening-tempering-normalizing treatment or forged hardening treatments.

Steels which can be employed in the process of the present invention are low, medium carbon steels or low alloy steels, as well as any other steels which are suitable for forging. However, generally, carbon steels containing 0.1 to 0.6% carbon, up to 1.0% silicon, and up to 2.0% manganese, or alloy steels containing one or more of the alloying elements of up to 4% nickel, up to 2% chromium, up to 1.0% molybdenum, up to 0.05% boron, up to 0.5% niobium and the like can be used.

Having now fully described the invention, it will be apparent to one of ordinary skill in the art that many changes and modifications can be made thereto without departing from the spirit or scope of the invention as set forth herein.

What is claimed as new and intended to be secured by Letters Patent is:

1. A process of hot forging a carbon or low alloy steel, which comprises the steps of:

working a steel;

hardening said worked steel at a temperature of at least the Ac_1 transformation point of the steel; and

hot forging said steel at a temperature in the range from 450°C to the Ac_1 transformation point of the steel.

2. The process of claim 1, which further comprises:

forging a steel which has two austenite and ferrite phases at a temperature ranging between the Ac_1 transformation point and the Ac_3 transformation point, and then hardening said forged steel prior to said hot forging.

3. The process of claim 1, which further comprises:

forging a steel which has two austenite and ferrite phases at a temperature ranging between 50°C less than the Ac_3 transformation point and the Ac_3 transformation point, and then

hardening said forged steel prior to said hot forging.

4. The process of claim 1, which further comprises:

forging said steel at a temperature of at least the Ac_3 transformation point, and then

hardening said steel prior to said hot forging.

5. The process of claim 1, which further comprises:

hardening said steel at a temperature of at least the Ac_3 transformation point prior to said hot forging.

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