(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 867 521 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
30.09.1998 Bulletin 1998/40

(51) Int. Cl.[6]: **C22C 38/18**, C22C 38/02, C22C 38/04

(21) Application number: **98300675.0**

(22) Date of filing: **30.01.1998**

(84) Designated Contracting States:
AT BE CH DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: **26.03.1997 FI 971257**

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(54) Steel for cold forging and a method using the steel

(57) Disclosed is a steel suitable for manufacturing cold-forgeable objects with good machinability, in particular objects having a geometrical form causing special difficulties in cold forging. In addition to iron and incidental impurities, the steel comprises the following contents in percent by weight:

C from 0.04 to 0.14, preferably from 0.04 to 0.12
Si from 0.01 to 0.35, preferably from 0.01 to 0.25
Mn from 0.2 to 1.0, preferably greater than 0.6
Cr from 1.0 to 2.0, preferably from 1.0 to 1.4
Mo from 0 to 0.25
S from 0.015 to 0.10
Al from 0 to 0.1
B from o to 0.015, preferably about 0.004
Ti from 0 to 0.05
Ca from 0 to 0.01, preferably from 0.0015 to 0.01
P from 0 to 0.035, preferably from 0 to 0.0025,

wherein the ratio Mn/S is greater than 10, and preferably greater than 20. The steel is hot rolled and, when necessary, also annealed before cold forging.

EP 0 867 521 A1

Description

This invention relates to steels suitable for manufacturing cold forgeable objects with good machinability, in particular objects having geometrical forms which would normally cause special difficulties in cold forging.

Steels having good cold forgeability are known, for example those manufactured according to the cold forging steel standard ISO 4954:1993 such as CC11X or CC11A and CC21K or CC21A. However, steels of this type cannot be subjected to heat treatment, and the hardening achievable by cold working of such steels is limited, which places limits on the kind of objects which may be manufactured from them. Cold working affects the lattice structure of the material. It gives rise to lattice defects, e.g. dislocations, and this raises the strength of the material and reduces its ductility. The strength of a cold worked object may vary in different parts of the object, since it is dependent on the degree of cold working. Wear resistance cannot be improved by mere cold working, and fatigue strength of an object hardened by cold working usually remains weak.

It is known to manufacture gears in part by cold forging. However, toothing of the gears is usually achieved by machining, which breaks the flow pattern of the material and weakens the mechanical properties of the gear. Gears and other cold forged objects cannot usually be manufactured solely by cold forging, as it is almost always necessary to carry out machining after cold forging. Machining of cold forged objects is problematic because of the microstructural changes and internal stresses caused by cold working. These problems manifest themselves, for example, as long chips and built-up edges, which impair the quality of the machined surface of the object. Though it is technically possible to carry out toothing by cold forging, the types of steels presently used for gears are not suitable for cold forging, mainly due to their strength and hardness.

The invention seeks to provide an improved cold forgeable steel from which high quality cold forged objects may be manufactured economically and simply. The invention thus provides a steel according to claim 1, and also extends to a billet according to claim 7, an object according to claim 8, and a method according to claim 9.

The essence of the invention is to combine good cold forgeability, great final strength, good ductility, toughness and good machinability, which is achieved by a correctly balanced composition of the steel. Cold forgeability is usually weakened by components which raise the strength of the steel. The composition of the steel is optimized by keeping the carbon, manganese, silicon and phosphorus content low and by alloying the steel with chromium, sulphur and possibly also boron. Carbon, silicon and manganese, in particular, raise the strength of the steel, influencing the microstructure of the steel after annealing. Manganese also raises the strength of the steel by influencing the microstructure of the steel after hot rolling. The final strength of the object can be improved by inclusion of chromium and boron, without weakening its cold forgeability. A steel with sulphur may be hot short, if the manganese content is too low. Hot shortage gives rise to internal defects in the cast billet in continuous casting, which in the cold forging stage may cause cracking of the worked object. The characterising proportion of manganese and sulphur according to the invention is important, because manganese advantageously influences castability, reducing the risk of internal cracking, and sulphur improves the machining properties of the object by lessening the amount of long chips. Therefore, the steel should preferably contain at least 0.015 percent by weight of sulphur.

The cold forgeable steel billet is preferably manufactured of a material whose carbon content is at most 0.12, preferably at most 0.09 percent by weight. A greater carbon content may cause an excessive rise in the strength in the annealed steel, which weakens cold forgeability. On the other hand a smaller carbon content lowers the strength of hardened steel, which for many applications is not desirable.

The manufacturing of steel becomes more difficult when the silicon content is lowered, but on the other hand silicon weakens the cold forgeability of the steel. Therefore it is recommended that the silicon content is at most 0.25 percent by weight.

The preferable value for the manganese content is greater than 0.6 percent by weight. For cold forging the lower the manganese content the better, but a manganese content which is too low makes the manufacturing of the steel difficult, for example by giving rise to internal defects, such as heat cracks, in the casting phase. A manganese content that is too high increases the segregation tendency of manganese and other elements, e.g. carbon and sulphur, during the solidification of the steel.

Cold forgeability decreases with increasing phosphorus content, but on the other hand the manufacturing of the steel becomes more difficult with a low phosphorus content. The maximum amounts according to the invention are intended to minimise the disadvantages caused by phosphorus.

Chromium is only slightly or not at all disadvantageous to cold forgeability. Its purpose is to give the steel a sufficient hardenability. The hardenability may also be improved by manganese, but manganese is much more disadvantageous for cold forgeability. In steels according to the invention the chromium content of 1.0 to 2.0 percent by weight has an almost insignificant effect on the cold forgeability. Usually, a sufficiently good hardenability is achieved when the chromium content is at most 1.4 percent by weight.

A small boron content, about 0.004 percent by weight, gives the steel hardenability. Boron does not weaken cold forgeability.

An addition of calcium improves machinability by modifying the composition and morphology of the non-metallic enclosures (sulphides and oxides) in the steel, but this improvement only occurs if the steel does not contain titanium. However, titanium is often added to protect boron against nitrogen, in which case calcium does not have an improving effect on machinability. Conventional steel manufacturing usually provides some calcium in the steel, generally about up to 0.0015 percent by weight.

One advantage of steel composed according to the invention is that a billet of the steel in a hot rolled condition may have a tensile strength of at most about 550 N/mm^2 and a hardness of at most about 160 HB, before cold forging. If the steel is in an annealed condition, the corresponding values are: tensile strength at most about 450 N/mm^2 and hardness at most about 135 HB before cold forging. These values are advantageous for cold forgeability.

Steels according to the invention are especially suitable for heat treatment in order to raise the final strength of the manufactured object. The manufactured object may be through hardened, or case hardened by carburizing hardening or nitrocarburizing hardening after cold forging. Surface hardening, for example by induction, flame, laser or electron beam welding methods may also be carried out.

Through hardening gives high yield strength and high fatigue strength. Case hardening and surface hardening are also advantageous for improving fatigue strength.

Case hardening improves both bending fatigue strength (which, in the case of a gearwheel, has an effect on, for example, the dynamic strength of the root of the gearwheel), and rolling contact fatigue strength (which has an effect on the dynamic strength of the tooth side of the gearwheel).

Surface hardening gives a better fatigue strength than through hardening, but a weaker rolling contact fatigue strength when compared to case hardening.

Case hardening of steels according to the invention by carburizing or nitrocarburizing gives good wear resistance, because these hardening methods give a high surface hardness, of at least 700 HV. With surface hardening, the HV. surface hardness usually remains at a level of around 500

The hardening method used will depend on the intended use of the object.

Quenching in relation to hardening is usually done in water, oil or polymeric emulsion, gas (e.g. nitrogen or argon), or in a fluidized bed. Due to their low carbon content, steels according to the invention may be quenched in water without risk of cracking, which is advantageous since water is cheap, environmental friendly, readily available and does not contaminate the manufactured object. However, water may cause dimensional changes, which may be avoided by carrying out quenching by using one of the other quenching means.

Conventionally, tempering is used for making the steel more ductile or tough. As a result of the low carbon content of steels according to the invention, tempering is usually not necessary, which lowers the manufacturing costs, increases throughput and reduces the risk of faults during manufacturing.

Furthermore, steels according to the invention do not always have to be annealed, which is usually necessary for cold forging. Due to the good cold forgeability of the steels of the invention, several cold forging stages can be carried out without interstage annealings, which substantially reduces the manufacturing costs. Moreover, the high ductility of the steels of the invention means that even relatively slim workpieces such as steering racks are well able to withstand the cold straightening caused by distortion due to hardening.

Hot rolled steel according to the invention, for example in the form of bars, threads or pipes, may readily be cold forged to produce substantially rotationally symmetric objects, such as axles, gearwheels, valve lifters, and the like. After hot rolling, and before cold forging, the steel billet is cooled. Cooling may be carried out by known techniques in a cooling bed or by means of retarded cooling, for example by preventing convection or using a cooling tunnel. By slowing down the transfer of heat from the steel billet, the steel is given a lower hardness and better cold forgeability, without substantial additional cost. The hardness of a steel that has only been hot rolled may in some cases be too high for achieving desired cold forgeability.

For objects in which forging is especially difficult, for example those having a small radius of curvature or a complex form, annealing may advantageously be carried out prior to cold forging. Such objects include, for example, gears, where the toothing is also made by cold forging. Three main methods may be used in annealing, namely supercritical annealing (spheriodizing), isothermal perlitizing or subcritical (isothermal) annealing. Supercritical or subcritical annealing is usually used for maximizing cold forgeability. Isothermal perlitizing is a short annealing which usually does not weaken machinability in the same way as other annealing methods.

The methods described above are applied to the billet and/or manufactured object with the aim of achieving a sufficiently high final strength. By using water quenching, for instance, a yield strength of about 800 N/mm^2 and an impact strength, measured by a V-notched bar (KV + 20°C), of about 50 J may be reached when the carbon content of the steel is more than 0.05 percent by weight and the thickness of the object at most 80 mm. When the carbon content rises above 0.1 percent by weight, the yield strength of the object may be about 900 N/mm^2.

Set out below, by way of example, are the compositions in wt% (in addition to iron and incidental impurities) of three steels manufactured according to the invention, together with various measured mechanical properties of the steels, mainly relating to their ductility. Steels 1 and 3 were tested in a hot rolled condition, whereas steel 2 was tested in both a hot rolled condition and with subsequent annealing.

Steel	1	2	3
C	0.06	0.08	0.12
Si	0.33	0.30	0.09
Mn	1.00	0.92	0.87
Cr	1.23	1.17	1.32
Mo	0.11	0.10	0.03
S	0.082	0.030	0.017
Al	0.02	0.04	0.03
B	-	0.004	0.004
Ti	-	0.02	0.02
Ca	0.001	0.001	0.001
P	0.018	0.011	0.016

Steel	1	2	2	3
	Hot rolled	Hot rolled	Annealed	Hot rolled
Yield stress (Re) N/mm^2	220	270	250	300
Tensile Strength (Rm) N/mm^2	420	480	410	490
Elongation (A5) %	39	30	34	34
Reduction of area (Z) %	75	62	76	76
Hardness (HB)	130	140	125	150

The invention is not limited to the embodiments disclosed, but several variations thereof are feasible, including variations which have features equivalent to, but not necessarily within the literal meaning of, features in any of the attached claims.

Claims

1. A steel suitable for manufacturing cold-forgeable objects with good machinability, characterised in that, in addition to iron and incidental impurities, the steel comprises the following contents in percent by weight:

   C from 0.04 to 0.14
   Si from 0.01 to 0.35
   Mn from 0.2 to 1.0
   Cr from 1.0 to 2.0
   Mo from 0 to 0.25
   S from 0.015 to 0.10
   Al from 0 to 0.1
   B from 0 to 0.015
   Ti from 0 to 0.05
   Ca from 0 to 0.01

P from 0 to 0.035,

wherein the ratio Mn/S is greater than 10.

2. A steel according to claim 1, wherein the carbon content is in the range 0.04 to 0.12 percent by weight, the silicon content is in the range 0.01 to 0.25 percent by weight, the manganese content is greater than 0.6 percent by weight, the chromium content is in the range 1.0 to 1.4 percent by weight, the boron content is approximately 0.004 percent by weight, the calcium content is in the range 0.0015 to 0.01, and the phosphorus content is not greater than 0.025 percent by weight.

3. A steel according to claim 1 or claim 2, wherein the ratio Mn/S is greater than 20.

4. A steel according to any of claims 1 to 3, wherein the carbon content of the steel is at most 0.09 percent by weight.

5. A steel according to any preceding claim, further characterised in that, in its rolled condition, the steel has a tensile strength of at most about 550 N/mm^2, and a hardness of at most about 160 HB, before cold forging.

6. A steel according to claim 5, wherein, in an annealed state, the tensile strength is at most about 450 N/mm^2, and the hardness is at most about 135 HB, before cold forging.

7. A billet for use in the manufacture of a cold forgeable object with good machinability, characterised in that the billet is composed of a steel according to any preceding claim.

8. An object with good machinability manufactured by using cold forging, characterised in that the object is composed of a steel according to any of claims 1 to 6.

9. A method of manufacturing a cold-forgeable object with good machinability, characterised in that the method comprises the steps of: forming an object from at least one billet composed of a steel according to any of claims 1 to 6; and hot rolling the steel.

10. A method according to claim 9, further comprising the step of annealing the steel prior to cold forging.

11. A method according to claim 9 or claim 10, further comprising the step of through hardening the object, or the step of hardening the object, after cold forging, ether with or without tempering.

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EUROPEAN SEARCH REPORT

Application Number
EP 98 30 0675

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	PATENT ABSTRACTS OF JAPAN vol. 095, no. 011, 26 December 1995 & JP 07 207423 A (NIPPON STEEL CORP), 8 August 1995, * abstract * ---	1-11	C22C38/18 C22C38/02 C22C38/04
Y	PATENT ABSTRACTS OF JAPAN vol. 010, no. 203 (C-360), 16 July 1986 & JP 61 044159 A (KOBE STEEL LTD), 3 March 1986, * abstract * ---	1-11	
Y	VEREIN DEUTSCHER EISENHÜTTENLEUTE: "Wekstoffkunde Stahl; Band 2: Anwendung" 1985 , SPRINGER-VERLAG XP002070259 * page 195; table D6.2 * ---	1-11	
Y	EISENHÜTTE ÖSTERREICH: "Spurelemente in Stählen" 1985 , VERLAG STAHLEISEN , DÜSSELDORF XP002070260 * page 20, paragraph 5.2.2; figure 5.4 * ---	1-11	TECHNICAL FIELDS SEARCHED (Int.Cl.6)
			C22C
A	PATENT ABSTRACTS OF JAPAN vol. 096, no. 002, 29 February 1996 & JP 07 286257 A (NKK CORP;OTHERS: 02), 31 October 1995, * abstract * ---		
A	PATENT ABSTRACTS OF JAPAN vol. 095, no. 008, 29 September 1995 & JP 07 118732 A (NKK CORP), 9 May 1995, * abstract * --- -/--		

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	3 July 1998	Ashley, G

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	PATENT ABSTRACTS OF JAPAN vol. 018, no. 215 (C-1191), 18 April 1994 & JP 06 010091 A (NIPPON STEEL CORP), 18 January 1994, * abstract * -----		
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)

The present search report has been drawn up for all claims

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MUNICH	3 July 1998	Ashley, G

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