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(54) **Forging and a method for its manufacture.**

(57) An improved forging with favourable strength features and toughness is produced of a material which in addition to iron and incidental impurities consists of the following elements in percent by weight :

- C from 0.04 to 0.14
- Si from 0.05 to 0.50
- Mn from 0.6 to 1.0
- Cr from 1.0 to 2.0
- Mo from 0.04 to 0.25
- S from 0 to 0.15
- Al from 0 to 0.1
- B from 0 to 0.015
- Ti from 0 to 0.05

The billet is forged within a temperature range of 800°C to 1300°C and that the billet, which has then become a forging, is quenched immediately after the forging procedure. Water or a water-based emulsion or solution is generally used for the quenching.

The invention relates to an improved forging with favourable strength features and toughness and a method of manufacturing the forging.

From EP-B-191873 a method for producing a directly quenched hot forging with favourable strength properties is known. The present invention seeks to improve this known technique so that the strength of the component, in particular the uniformity of the strength over the cross-section of the component, and the toughness of the component in direct quenching are improved.

The strength features of a forging can in principle be improved by the following means:

- raising the carbon content
- raising the manganese content
- raising the chromium content
- alloying with nickel
- alloying with molybdenum.

Raising the carbon content increases the strength effectively, but high contents, especially contents substantially over 0.1%, impair toughness and machinability.

Raising the manganese content to more than 1% is in many cases useful, but manganese has a strong tendency to segregation. This easily causes quite large strength variations over the cross-section of a component and between components in continuous production. In addition, the segregation of manganese impairs the machinability of the steel.

Raising the chromium content to more than 2% impairs the toughness, especially when the carbon content is more than 0.06%. On the other hand, chromium has a low tendency to segregation, so that not even contents above 1% impair machinability.

Alloying with nickel is quite an expensive measure and its influence on the strength is relatively low, especially at low contents.

Alloying with molybdenum is not a very popular measure, because molybdenum is an expensive alloying element and its effect on improving the strength decreases the more the content increases. In addition, the bainite formation caused by molybdenum usually impairs toughness, especially if the carbon content is 0.15% or higher.

According to the present invention an improvement of the known technique is achieved by adding small amounts of molybdenum, so that the molybdenum content is 0.04 to 0.25 percent by weight, preferably 0.04 to 0.15 percent by weight.

The present invention therefore provides a forging with favourable strength features and toughness, characterised in that it is produced of a material, which in addition to iron and incidental impurities has the following material contents in percent by weight

C	from 0.04 to 0.14, preferably from 0.07 to 0.14
Si	from 0.05 to 0.50
Mn	from 0.6 to 1.0
Cr	from 1.0 to 2.0

Mo	from 0.04 to 0.25, preferably from 0.04 to 0.15
S	from 0 to 0.15, preferably from 0.02 to 0.15
Al	from 0 to 0.1
B	from 0 to 0.015
Ti	from 0 to 0.05

and that the component has been hot forged within a temperature range of 800°C to 1300°C and immediately thereafter quenched.

The invention also provides a method for producing an improved forging with favourable strength features and toughness, characterised in that the billet for the desired improved forging is produced of a material which in addition to iron and incidental impurities consists of the following elements:

C	from 0.04 to 0.14 percent by weight
Si	from 0.05 to 0.50 percent by weight
Mn	from 0.6 to 1.0 percent by weight
Cr	from 1.0 to 2.0 percent by weight
Mo	from 0.04 to 0.25 percent by weight
S	from 0 to 0.15 percent by weight
Al	from 0 to 0.1 percent by weight
B	from 0 to 0.015 percent by weight
Ti	from 0 to 0.05 percent by weight

that the billet is forged within a temperature range of 800°C to 1300°C and that the billet, which has then become a forging, immediately after the forging procedure is quenched in water or in a water-based emulsion or solution.

By alloying a steel according to the invention with molybdenum the strength can be raised effectively at low contents. This is caused by the high hardenability factor of molybdenum, especially when the carbon content is low, as in the invention. Further, the introduction of a new alloying element has a synergistic effect on hardenability, in other words, a new alloying element improves hardenability more effectively when employed together with other alloying elements (in this case manganese and chromium) than when employed alone.

Molybdenum also favours the formation of bainite, which can be seen, for example, in a so-called CCT-diagram as a wide area of bainite. The wide bainite area minimises the strength difference between the surface and the core, because the formation of martensite on the surface can be prevented, which results in that the component becomes practically fully bainitic. In addition, a wide bainite area means in practice that the quenching rate used is not very critical, so that quite a wide range of quenching rates may be used. In quenching large cross-section components the quenching rate is by necessity relatively low, but this does not cause any essential disadvantages when applying the invention.

Experiments have shown that, in a steel according to the invention, molybdenum does not impair toughness but improves it. The relatively high price of molybdenum restricts its economical use to low contents. However, with regard to its effect on improving

hardenability, molybdenum is a considerably cheaper alloying element than for instance nickel. In a steel according to the invention the molybdenum content is at the most 0.25 percent by weight and a preferred content is at the most 0.15 percent by weight, whereby the synergistic effect of molybdenum on hardenability is at its peak. At increasing contents of molybdenum its effect on hardenability per content unit decreases.

A quenching technique can be used for minimising non-uniformity in strength. By quenching a forging in water or in a water-based (polymer) emulsion or solution sufficiently uniform strength properties over the cross-section of the component are normally obtained when using a steel according to the invention. Water is usually the most desirable quenching fluid. Other substances may be added to the water so that a water-based emulsion or solution is formed. This has an influence on the quenching effect of the water.

The quenching effect of water may also be influenced by controlling its temperature. By raising the water temperature over room temperature, preferably to a temperature of over 30°C or 40°C, the best results are usually obtained. Another recommendable quenching technique, when applying the invention, is spray quenching, because its adjustability is outstanding. The effect of spray quenching can easily be adjusted and the quenching can be directed to only a part of a component. Thereby only the desired portion of the component becomes hardened, while the other portions remain soft and tough.

A particularly preferred steel according to the invention consists in addition to iron (and incidental impurities) the following contents of other elements, in percent by weight: C 0.06%, Si 0.28%, Mn 0.91%, S 0.080%, Cr 1.11%, Al 0.038%, Mo 0.10%, Ti 0.019%, B 0.005%.

A steel billet according to the invention is well suited not only as a directly quenched hot forging billet, but also for cold forming either rapidly annealed or directly hot-rolled without annealing.

A steel according to the invention is also well suited for nitriding or nitrocarburising. Molybdenum improves the resistance to softening during tempering, which improves the core strength at nitriding. In addition, molybdenum has an effect on preventing temper embrittlement, which improves the toughness, in particular if the component is nitrided.

Forging billets according to the invention may be cold cropped from continuous cast or hot-rolled steel bars and the finished forging may be directly quenched from the forging temperature. Forgings according to the invention may be machined and used without tempering.

Forgings may be assembled also by fusion welding of several component parts.

A steel according to the invention is very well suited also for carburising hardening. The advantage is then that core elongation and toughness exceed nor-

mal values, which is caused by the lower than usual carbon content of the steel. This allows the use of the steel in particular in such carburising hardened elements in which large deformations occur and which for that reason must be straightened, for example by cold-straightening.

It has been experimentally established that the machinability of a steel according to the invention is clearly better than that of normal steels (containing more carbon and often also more manganese). The better machinability has been observed as a lower wear in high speed steel cutting edges.

The strength and toughness of a component according to the invention can be improved by controlling relatively carefully the end temperature of the hot forging. The most preferred end temperature of the forging is 950°C to 1050°C. Another way of increasing the strength is to avoid very low carbon contents. It is recommended that the carbon content is at least 0.07 percent by weight/ In general terms the carbon content should preferably, within the limits of the invention, be sufficiently high that the tensile strength of the finished forging is, without tempering, at least 900 N/mm².

By adding a small quantity of sulphur to a steel according to the invention, at least 0.02 percent by weight, the machinability of the steel can be improved quite significantly. The sulphur content should not be more than 0.15 percent by weight, above which value the mechanical properties are impaired.

The invention is also illustrated in the accompanying drawing which is a CCT-diagram showing the structure of a forging according to the invention (preferred composition) at different quenching rates. The horizontal axis of the diagram shows the time in seconds and the vertical axis the temperature in degrees centigrade. The martensite area is indicated by the letter M, the bainite area by the letter B, the ferrite area by the letter F and the perlite area by the letter P. The areas have been determined by using different heating temperatures of test samples. The set of curves shown in full lines reflects the situation when the heating has been to 1200°C, the broken line curves show heating to 900°C and dotted line curves show heating to 1200°C as well as forming of the test sample by upsetting to 50 percent area reduction. As is evident from the diagram, a large quenching rate area, from about 0.2 to about 30°C/s, is available for achieving the desired fully bainitic structure. Quenching rates above 30°C/s may also be used, because a slight martensite formation does not usually cause problems. Additionally it can be seen that the CCT-curves are almost independent of the heating temperature and of the degree of deformation. This means that the structure and hence the mechanical properties of a forging made of a preferred composition according to the invention are almost independent of how the hot forging is started.

The invention is not limited to the disclosed examples since several modifications are feasible within the scope of the following claims.

Claims

1. A forging with favourable strength features and toughness, **characterised in that** it is produced of a material, which in addition to iron and incidental impurities has the following material contents in percent by weight

C	from 0.04 to 0.14, preferably from 0.07 to 0.14
Si	from 0.05 to 0.50
Mn	from 0.6 to 1.0
Cr	from 1.0 to 2.0
Mo	from 0.04 to 0.25, preferably from 0.04 to 0.15
S	from 0 to 0.15, preferably from 0.02 to 0.15
Al	from 0 to 0.1
B	from 0 to 0.015
Ti	from 0 to 0.05

and that the component has been hot forged within a temperature range of 800°C to 1300°C and immediately thereafter quenched.

2. A forging according to claim 1, **characterised in that** its quenching has been performed in water or in a water-based emulsion or solution, the temperature of which preferably is above room temperature.

3. A method for producing an improved forging with favourable strength features and toughness, **characterised in that** the billet for the desired improved forging is produced of a material which in addition to iron and incidental impurities consists of the following elements:

C	from 0.04 to 0.14 percent by weight
Si	from 0.05 to 0.50 percent by weight
Mn	from 0.6 to 1.0 percent by weight
Cr	from 1.0 to 2.0 percent by weight
Mo	from 0.04 to 0.25 percent by weight
S	from 0 to 0.15 percent by weight
Al	from 0 to 0.1 percent by weight
B	from 0 to 0.015 percent by weight
Ti	from 0 to 0.05 percent by weight

that the billet is forged within a temperature range of 800°C to 1300°C and that the billet, which has then become a forging, immediately after the forging procedure is quenched in water or in a water-based emulsion or solution.

4. A method according to claim 3, **characterised in that** the molybdenum content of the material is 0.04 to 0.15 percent by weight.

5. A method according to claim 3 or 4, **characterised in that** the temperature of the quenching liquid is kept above room temperature, preferably at a temperature above 30°C.

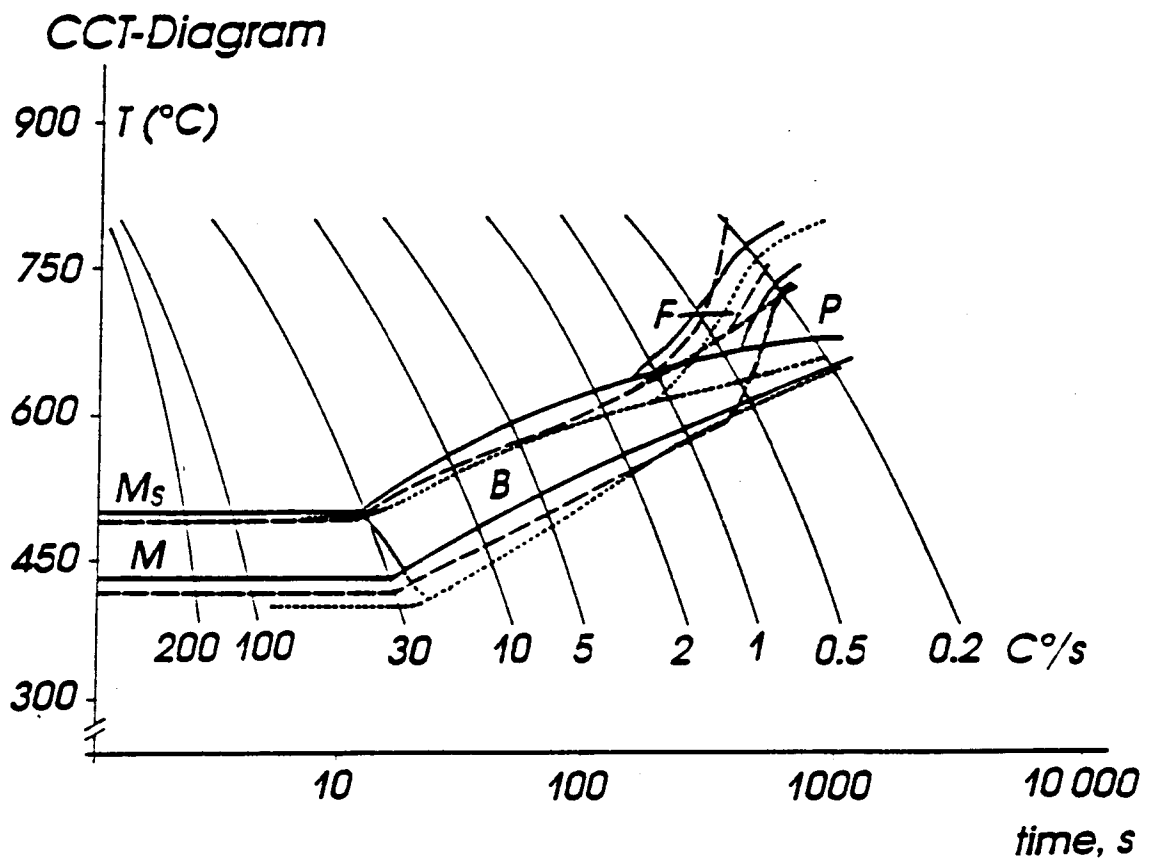
6. A method according to any of claims 3 to 5, **characterised in that** the end temperature of the hot forging of the billet is 950°C to 1050°C.

7. A method according to any of claims 3 to 6, **characterised in that** the carbon content of the material is at least 0.07 percent by weight.

8. A method according to any of claims 3 to 7, **characterised in that** the carbon content of the billet is kept at such a high level that the tensile strength of the forging is, without tempering, at least 900 N/mm².

9. A method according to any of claims 3 to 8, **characterised in that** the sulphur content of the material is at least 0.02 percent by weight.

10. A method according to any of claims 3 to 9, **characterised in that** the quenching is performed by spray quenching either the whole forging or just a desired portion thereof.





European Patent
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EUROPEAN SEARCH REPORT

Application Number
EP 93 30 6710

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.5)
Y	DE-C-749 477 (DEUTSCHE EDELSTAHLWERKE A.G. & KOHLE-UND EISENFORSCHUNG GMBH) * the whole document * ---	1, 3, 4	C22C38/22 C21D1/02
Y	US-A-3 348 981 (GODA ET AL.) * the whole document * ---	1, 3, 4	
A	US-A-4 711 676 (KITAORI ET AL.) * the whole document * ---	1, 3	
A	DE-C-927 213 (OBERHÜTTEN VEREINIGTE OBERSCHLESISCHE HÜTTENWERKE AKTIENGESELLSCHAFT) * the whole document * -----	1, 3	
			TECHNICAL FIELDS SEARCHED (Int.Cl.5)
			C22C C21D
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 25 November 1993	Examiner Lippens, M
CATEGORY OF CITED DOCUMENTS		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document			

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