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ALLOY STEEL

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This invention relates to an improved steel characterized by high strength and ductility. The high strength and ductility is most phenomenal when the steel is in a normal condition; that is, in the "as cast", "as rolled", "as forged", or as "cast and annealed" states, but without having received any special heat-treatment such as normalizing, quenching, drawing, etc.

The present day carbon or alloy steels after drawing from the quenched or annealed states increase in ductility, but invariably lose in strength, or if they show a slight increase in strength they manifest a marked loss in ductility and resistance to shock. The present invention further contemplates a steel which, after drawing from the annealed condition, shows a marked increase in strength with equal and often increased ductility.

Another object of this invention is the provision of a low carbon steel having tensile strength and ductility in excess of that possessed by the usual carbon steel. Still another object of this invention is the provision of a low carbon copper steel, and a copper-silicon steel, both characterized by high tensile strength and ductility.

This invention also contemplates the provision of a low carbon copper silicon steel characterized by properties of high elastic strength and ductility and which may be used in the "as cast" or "as forged" condition, and withal possesses good machining properties.

The strength of carbon steel is primarily due to the presence of iron carbide and it is well known that the strength of carbon steel may be modified or affected by the presence of other elements such as manganese, chromium, vanadium, molybdenum, tungsten, etc., depending upon their particular percentages. With existing processes only a certain ratio of iron and carbon will combine to form carbide of iron, the remainder of these elements retain their freedom, and under certain conditions the free carbon becomes graphitic carbon which segregates and weakens the metal.

This invention consists of a combination of elements with low carbon content which, in the absence of injurious carbides, are free to operate towards the production of the special properties of strength and ductility which we have described.

Marked results are also obtained when copper and silicon in certain ratios are introduced into substantially pure iron; the resultant steel possessing a high degree of elastic strength and exceptional ductility.

The use of copper, however, as an ingredient of steel is attended by certain drawbacks since it is soluble in iron only to a very moderate extent and when used above this limited percentage some of it tends to separate from solid solution during the selective freezing of the steel, thereby greatly reducing ductility and hot malleability. Carbon has a marked effect in further lowering the solubility of copper when present in amounts much over .15% and with the usual amount of silicon (.4% and under), the solubility is so reduced that even 1.0% copper seriously impairs the ductility of the metal. It is obvious, therefore, that excessive copper in a carbon steel alloy is a detriment. However, when the silicon is raised to .8%, or somewhat over, there occurs a very favorable change, so that when carbon is even a little in excess of .2% the steel will still exhibit good ductility. Either silicon combines with some of the carbon, or it lowers the upper transformation point so that there is a lagging or retardation in the action of the forces within the molten mass, known as hysteresis, providing a wider transformation range through which the copper may enter into solid solution. The presence of this comparatively large amount of silicon also greatly increases the tensile properties of this low carbon-copper alloy, which may be tempered and hardened without any increase in carbon. This silicon ratio produces the strength which in other copper steels is obtained by carbon, but it does so without the usual loss in ductility, caused by the copper separating at the freezing point as in the former low silicon copper steels.

In this manner we produce an alloy with low carbon content containing over 1% copper, by means of the addition of silicon in greater ratio as described above, and as will be set forth in detail later. The alloy will have high strength along with high ductility and shock resistant properties.

A combination of these elements will have a lower melting and freezing temperature than iron carbide and in certain ratios will enter into solid solution, and their mutual affinities will determine the amounts remaining in solid solution. The lowering of the transformation point also increases the strength characteristic of the alloy.

This invention proposes a combination of elements with copper the chief strengthening agent, but in such ratios with other ingredients as to render the copper non-deleterious in the metal, and thus provide a compound which of itself will function as a strengthening agent in addition to the carbon.

Considering the statement just made, our experiments have proved that an increase in the amount of silicon, to proportions which are more specifically pointed out hereinafter, has this result. More particularly, this invention proposes the addition of silicon to an amount at least sufficient to combine with the copper whereby to

form a constituent which in itself essentially increases the strength of the alloy. Tests have shown that the alloy is improved when the silicon content thereof is increased over that normally present in iron, and within the limits specified hereinafter.

When carbon is present in an alloy to an amount slightly in excess of .2%, along with copper and increased silicon in proper ratio, the resultant steel has exhibited good ductility and increased tensile strength. Further, the steel may be tempered and hardened without any increase in carbon content, and it has also been discovered that when the silicon content is increased, and carbon low, as more specifically mentioned hereinafter, the steel may be used in the "as cast" condition and exhibits excellent machining properties.

To accomplish the results mentioned above it has been found beneficial to add still another element—manganese—into the alloy in the ratio of about four parts manganese to four to six parts copper, which forms a copper-manganese compound which, in combination with the copper-silicon compound described above, produces the total strength of this alloy. If excess carbon exists in the alloy, however, the manganese will, by the preference of chemical affinity, combine with it rather than the copper, thus forming the deleterious manganese carbides which are difficult to break up and diffuse even with elaborate heat-treatment. But the copper-manganese compound precipitates out in the form of a ductile substance giving no evidence of brittleness. When, however, the manganese exceeds the above ratio a more brittle precipitate is liberated. In practice the manganese should not be much less than half the copper, otherwise poor forging properties will result.

We have discovered that manganese has a greater affinity for copper than it has for carbon since the copper apparently decomposes the manganese carbide uniting with the new free manganese and liberating carbon. The results produced on this alloy by the application of this discovery is an important part of the invention.

As a specific example of the alloy of the present invention, iron is combined with elements in the ratio of carbon .138%, manganese 1.58%, phosphorus .023%, sulphur .016%, silicon 1.08%, copper 1.83%. Tests resulted in the following physical properties, after full annealing at 950 degrees centigrade for three hours;

Yield point	68,250 lbs. per sq. in.
Tensile strength	90,000 lbs. per sq. in.
Elongation in 2 in	26.55 per cent
Reduction in area	51.35 per cent

A second test, cut from the same coupon, but reheated, or drawn at 500 to 525 degrees centigrade showed increased properties as under;

Yield point	77,550 lbs. per sq. in.
Tensile strength	92,050 lbs. per sq. in.
Elongation in 2 in	29.65 per cent
Reduction in area	57.00 per cent

Without this increased silicon the ductility of this specimen would fall far short of the values given.

This alloy steel may be produced in any type of furnace, and the copper may be added either early or late during the operation, while the other elements, silicon and manganese, are preferably added near the finish of the heat, either in the furnace or in the ladle. Owing to the chemical affinity of copper and manganese a lesser percentage of manganese is lost in the melting process.

In the foregoing description the properties of this invention in the "as cast" and "as cast and annealed" have been stressed, however, it may be heat-treated and given exceptional qualities. It may also be mechanically formed. It may be either slowly or rapidly cooled depending upon the properties desired. This strengthening is the result of the particular ratio of copper, silicon and manganese, which form compounds of copper silicide and mangano-copper silicide, which precipitate out of solid solution as sub-microscopic particles, the amount of precipitation depending upon the temperature of the metal as drawn and the mass of the section.

From the above description it is believed that the present invention will be fully apparent to those skilled in the art; the alloy comprises a low carbon, high-silicon copper steel which possesses the characteristics mentioned herein. The low carbon steel alloy of the present invention contains copper to an amount approximately equivalent to the empirical combining ratios of the normally alloying constituents of the steel.

As set forth in the appended claims, the range of essential alloying ingredients is broadly as follows:

Carbon	trace to .20%
Manganese	.4% to about 1.58%
Silicon	.6% to 2.5%
Copper	.5% to 3.0%

Iron, balance, except for impurities.

What is claimed is:

1. A steel alloy containing carbon between .10% and under .20%, manganese between .4% to 1.5%, silicon between .6% and 2.0%, and copper between 1.0% and 2.5%, the balance iron, except for impurities.

2. The presence of copper in a steel to the extent of 1.5 to 2.0%, carbon .08 to under .20%, silicon 1.0 to 1.25%, manganese .4 to 1.5%, and the balance iron, except for impurities.

3. An alloy steel having high strength and good ductility in annealed condition containing as essential elements copper 1.5% to 2.0%, carbon .08% to under .20%, silicon 1.0% to 1.25%, manganese .4% to 1.5%, and the balance iron except for impurities, such as sulphur and phosphorus.

4. An alloy steel having high strength and ductility in its annealed state comprising as essential elements copper .5% to 3.0%, carbon trace to under .20%, silicon over .6% up to 2.5%, manganese .4% to approximately 1.58%, and the balance iron except for impurities, such as sulphur and phosphorus.

5. An alloy steel containing carbon trace to under .20%, copper .5% to 3.0%, silicon over .6% up to 2.5%, and manganese .4% to 1.5% as alloying ingredients dispersed in a matrix of iron substantially free from manganese carbide, the balance iron, except for impurities.

6. As a new article of manufacture, an alloy steel having high strength and ductility in its cast condition and containing manganese .4% to 1.5%, copper 1% to 2.5%, silicon .6% to 2.0%, and carbon trace to under .20%, the copper and silicon being in the form of copper silicide, the balance iron, except for impurities.

7. As a new article of manufacture, an alloy steel containing carbon trace to under .20%, copper .5% to 3.0%, silicon over .6% to 2.5%, manganese .4% to 1.5%, and the balance iron, the cop-

per content being in amount equal to or greater than the silicon content.

8. As a new article of manufacture, an alloy steel containing carbon .138%, manganese 1.58%, silicon 1.08%, copper 1.83%, phosphorus .023%, sulphur .016%, and the balance iron.

9. An alloy steel containing carbon .08% to less than .12%, manganese .8% to 1.5%, copper .6% to 1.5%, silicon .7% to 1%, and the balance iron except for impurities such as sulphur and phosphorus.

10. A low carbon copper silicon steel adapted on heat-treating to evidence an increase in strength and ductility, said steel containing in addition to iron the following elements only, not over .20% carbon; between .50 to 3.0% copper and between .60% and 2.5% silicon.

11. A low carbon copper silicon steel adapted on heat-treating to evidence an increase in strength and ductility, said steel containing in addition to iron the following elements only, not over .20% carbon; between .50 to 3.0% copper and between .60% and 2.5% silicon with manganese in amounts approximating 4 parts manganese to each 4 to 6 parts copper.

12. A low carbon copper silicon steel adapted on heat-treating to evidence an increase in strength and ductility, said steel containing in addition to iron the following elements only, not over .20% carbon; between .50 to 3.0% copper and between .60% and 2.5% silicon with manganese .4 to 1.5%, the manganese and copper being present in the ratio of 4 parts manganese to each 4 to 6 parts copper.

13. A low carbon steel adapted on heat-treating to evidence an increase in strength and ductility comprising carbon between .10% and .20%, silicon between .60% and 2.0% and copper between 1.0% and 2.5%, balance substantially all iron.

14. A low carbon steel adapted on heat-treating to evidence an increase in strength and ductility comprising carbon between .10% and .20%, silicon between .60% and 2.0% and copper between 1.0% and 2.5% with manganese .4 to 1.5%, said manganese being present in the ratio of 4 parts manganese to each 4 to 6 parts copper, balance substantially all iron.

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