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HIGH STRENGTH, LOW ALLOY STEELS

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This invention relates to low alloy, structural type steels and, more particularly, to a low alloy, high strength steel characterized by its ease of fabrication, and unusual balance of ductility and strength obtainable by heat treatment alone.

High strength materials presently available are of the expensive high alloy type or they are of a type the highest strength properties of which are too difficult to obtain by practical production methods because of their low ductility. There is a great need for a low cost, high strength material having improved ductility to afford ease of fabrication at such high strength conditions. Also, high strength to weight ratio is very desirable in a material for use in fabricating structures in which overall weight is an important factor.

It is an object of this invention to provide a low alloy, high strength steel having a high strength to weight ratio and sufficient ductility at such high strengths to allow normal type production fabrication.

Another object is to provide a low cost, low alloy, high strength steel which has adequate isothermal transformation characteristics to allow it to be easily worked in its metastable austenitic condition without causing strain induced transformation during working thus to resist cracking during forming or upon cooling.

These and other objects and advantages will be better understood from the more detailed description and illustrative examples.

Briefly stated, the alloy of this invention broadly provides a low alloy, high strength steel comprising by weight about 0.5–2% total of manganese, molybdenum and vanadium, 0.45–0.55% carbon, 4.5–7.5% nickel, 0.75–1.25% chromium, 1.75–2.25% silicon with the balance essentially iron and impurities.

The scope of the alloy of this invention and its advantages will be more clearly understood when viewed in connection with the following more detailed description and specific examples which are meant to be illustrative of rather than limitations on the scope of this invention. The scope of the invention will be pointed out in the appended claims.

It has been recognized in the evolution of this invention that complex interrelationships exist between various alloying elements which can be melted with iron to form workable, high strength, low alloy steels. The alloy of this invention in its broad composition and preferably including by weight 0.45–0.55% carbon, 4.5–5.5% nickel, 0.75–1.25% chromium, 1.75–2.25% silicon, 0.5–1% manganese, 0.4–0.6% molybdenum, 0.03–0.07% vanadium with the balance essentially iron and impurities is characterized by its combination of high strength and ductility through heat treatment alone as well as its sluggish transformation rates.

All alloying elements affect both the strength and hardenability of steel. Although the carbon is important in raising the strength of steels, too high a carbon content will result in a brittle alloy. Carbon is included in the alloy of this invention within the range of 0.45–0.55% by weight because within that range it is capable of developing high strength without resulting in undue lowering of the ductility. It is preferred that the carbon be maintained at about 0.5%. The inclusion of carbon at a rate much above the 0.55% by weight tends to increase brittleness whereas a lowering of the carbon range below about 0.45% tends to result in a weaker alloy.

Nickel within the range specified helps to increase the toughness and ductility of the alloy by significant amount. It also serves an important function on the hardenability of the alloy. The most effective way to increase the hardenability of an alloy is through increase in carbon content. However, because a high carbon content would tend to unduly increase brittleness, such an approach is not very desirable. The alloy of this invention increases hardenability not entirely by an increase in the carbon content but also by increasing the nickel content within the range specified, thereby avoiding undue embrittlement to the alloy. Less than the specified amount of nickel along with the same range of other elements results in an alloy having insufficient hardenability for warm working in the metastable austenitic condition. Nickel at more than about 7.5% and preferably not more than 5.5% by weight results in too much retention of the weaker austenite upon quenching.

The addition of silicon within the range of about 1.75–2.25% by weight tends to shift the temper embrittlement range to a higher temperature, minimize the extent of temper embrittlement and reduce softening due to tempering.

As has been mentioned before, all of the alloying elements affect both strength and hardenability of steels. However, the combination of alloying elements within the range specified results in sluggish isothermal transformation rates which provide the advantages of increasing the latitude of the temperature and time within which the steel can exist in its metastable austenitic condition. This broad latitude in time and temperature renders the steel more easily workable in its metastable austenitic condition without causing induced transformation.

It has been shown that low alloy steels can be significantly strengthened by working in the metastable austenitc condition followed by quenching and tempering. However, such practices may lead to cracking during working or upon cooling if transformation is induced by plastic deformation. The alloy of this invention has sufficiently sluggish isothermal transformation characteristics so that its tendency to induced transformation is less than that of similar steels. By avoiding induced phase transformation, the ease of fabrication is improved and the cost of fabrication is reduced. Thus the careful selection of the elements of the alloy of this invention within the range specified eliminates more costly production processing.

It should be recognized that the composition ranges specified herein may vary somewhat according to the degree of melting control available. The alloy is capable of any type of conventional melting for steels, but in any case, it is preferred that it be de-oxidized with aluminum.

Measures of the effect of alloying additions include comparison of mechanical testing data such as from tensile testing.

Table I below shows a comparison of the compositions of the alloy of this invention broadly (WCM) and in more specific forms (WCM–1 and WCM–3) with the compositions of some commercially available alloys (S and T). Although the differences in composition may appear at first to be slight, reference to the data of Tables II and III will show the significant variations in one or

more of the tensile properties unexpected from such seemingly narrow composition changes.

TABLE I

Compositions (percent by weight)

Steel	C	Ni	Cr	Si	Mn	Mo	V	Fe
WCM	.45-.55	4.5-5.5	.75-1.25	1.75-2.25	.5-1	.4-.6	.03-.07	Bal.
WCM-1	.5	5	1	2	.75	.5	.05	Bal.
WCM-3	.5	7.5	1	2	.75	.5	.05	Bal.
S	.5-.6	3.6	.95	2.1	.8	.5	.07	Bal.
T	.4-.45	1.65-2.0	.70-.95	1.45-1.80	.65-.90	.3-.45	.05	Bal.

The tensile data given in Table II below represents an average of numerous individual tests on materials within the composition range of the alloys shown. The tests were performed on 0.06–0.10" sheet material which had been austenitized at about 1700° F. and then oil quenched. The test material was refrigerated for one hour, where indicated, to bring about more complete martensitic transformation prior to tempering for one hour at 700° F.

As used in the tables, "UTS" means "Ultimate Tensile Strength," the value in pounds per square inch obtained when the maximum load recorded during the plastic straining of a specimen is divided by the cross-sectional area of the specimen before straining. "0.2% Y.S." means "0.2% Yield Strength," the stress at which a material exhibits 0.2% deviation from the proportionality of stress to strain. This figure is commonly used as the basis of design strength of articles. One tensile ductility test which measures the permanent deformation before fracture by stress in tension is reported in the tables as "Percent El" which means "Percent Elongation": the amount of permanent extension in the fracture area in the tension test.

TABLE II

AVG. tensile properties—heat treatment only

Group	Steel	Refrigeration, °F. for 1 hr.	UTS (1,000 p.s.i.	0.2% Y. S. (1,000 p.s.i.)	Percent El. (in 1")
1	WCM	None	284	246	13.5
2	S	None	271	230	6
3	T	None	283	239	8.5
4	WCM-1	−100	328	286	7
5	WCM-3	−100	312	266	7
6	S	[1] −100	327	286	3
7	WCM	−300	324	281	7
8	T	−300	287	244	6

[1] For 8 hours.

In Table II, groups 1, 4, 5 and 7 represent average tensile data for the alloy of this invention under various conditions shown; groups 4 and 5 represent more specific composition ranges. The alloys of groups 2, 3, 6 and 8 are outside the range of the alloy of this invention and have been included for comparison purposes. From a comparison of group 1 with groups 2 and 3, groups 4 and 5 with groups 6 and 8, and group 7 with group 8 it is readily seen that the alloy of this invention has a better balance of tensile strength and ductility over that of other alloys which represent the other best available steels. The test results for the alloys of groups 1, 4, 5 and 7 were consistent under a given set of conditions indicating uniformity of structure. However, the test results for alloys S and T under the same conditions were very erratic.

Referring to groups 1–3 of Table II, it is to be noted that, aside from consistency of data, alloy WCM has better yield strength and much better ductility than that of S and T alloys under the same conditions. Similarly, in groups 4, 5, 6 and 8, even though alloy S (group 6) was refrigerated for 8 hours to precipitate more of the stronger martensitic structure instead of only for one hour as in the case of alloys WCM–1 and WCM–3, and even though alloy T (group 8) was refrigerated at −300° F. instead of −100° F. for the same reasons, the alloys WCM–1 and WCM–3 show a better balance of strength and ductility. This is especially true of the alloy WCM–1. Alloy WCM–3, though exhibiting greatly improved ductility, has a slightly lower strength because of more retained austenite due to the added nickel content. Thus, as has been mentioned before, it is preferred that the alloy of this invention include 4.5–5.5% by weight nickel although the inclusion of as much as 7.5% nickel has been shown to have adequate strength with more than double the ductility of similar alloys outside the range of the alloy of this invention.

A further comparison between groups 7 and 8 shows alloy WCM to possess the same improved balance of strength and ductility.

Although the data of Table II reflects results of tests conducted after 700° F. tempering, similar results have been obtained under other conditions. For example, at tempering temperature of 600° F. for 1 hour alloy WCM after 1 hour refrigeration at −100° F. had elongation in 1" of 6%. By way of comparison, alloy S after 8 hours refrigeration at −100° F. had only a 3.5% elongation in 1".

This improved balance of strength and ductility is characteristic of the alloy of this invention after warm working in the metastable austenitic condition as well as in the heat treated form alone as shown in Table II above.

Table III shows that after warm working at 1000° F. within the metastable austenitic region followed by oil quenching, one hour refrigeration at −100° F. and tempering at 600° F. for one hour, alloy WCM–1 of this invention is considerably stronger than alloy T.

TABLE III

Average tensile properties warm worked in metastable austenite region

Steel	Work (percent)	UTS (1,000 p.s.i.)	0.2% Y.S. (1,000 p.s.i.)
WCM-1	65	400	354
T	60	328	290

By a careful selection of the alloying elements, this invention provides a steel having an improved balance of strength and ductility obtainable by heat treatment alone. Its increased hardenability and hence sluggish transformation as previously discussed, allows warm working in the metastable austenitic condition without transformation to hard-to-work phases. This steel's ability to avoid transformation during such warm working inhibits cracking of articles manufactured by such methods. Such cracking is generally caused by uneven contraction rates in other steels.

Although the alloy of this invention has been described in connection with specific examples, those skilled in the art will understand the modifications and variations of which this invention is capable.

What is claimed is:

1. A high strength, low alloy steel comprising by weight about 0.5–2% total of manganese, molybdenum and vanadium, 0.45–0.55% carbon, 4.5–7.5% nickel, 0.75–1.25% chromium, 1.75–2.25% silicon, with the balance essentially iron and impurities.

2. A high strength, low alloy steel comprising by weight about 0.5–2% total of manganese, molybdenum and vanadium, 0.45–0.55% carbon, 4.5–5.5% nickel, 0.75–1.25% of chromium, 1.75–2.25% silicon, with the balance essentially iron and impurities.

3. A high strength, low alloy steel comprising by weight about 0.5–1% manganese, 0.4–0.6% molybdenum, 0.03–0.07% vanadium, 0.45–0.55% carbon, 4.5–7.5% nickel, 0.75—1.25% chromium, 1.75–2.25% silicon, with the balance essentially iron and impurities.

4. A high strength, low alloy steel comprising by weight about 0.5–1% manganese, 0.4–0.6% molybdenum, 0.03–0.07% vanadium, 0.45–0.55% carbon, 4.5–5.5% nickel, 0.75–1.25% chromium, 1.75–2.25% silicon, with the balance essentially iron and impurities.

5. A high strength, low alloy steel comprising by weight about 0.75% manganese, 0.5% molybdenum, 0.05% vanadium, 0.5% carbon, 5% nickel, 1% chromium, 2% silicon, with the balance essentially iron and impurities.

6. A high strength, low alloy steel comprising by weight about 0.75% manganese, 0.5% molybdenum, 0.05% vanadium, 0.5% carbon, 7.5% nickel, 1% chromium, 2.% silicon, with the balance essentially iron and impurities.

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