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(54) **High strength steel alloy and strip and sheet product made therefrom**

(57) An alloy is disclosed that provides a unique combination of very high strength, toughness, and ductility. The alloy can be characterized by the following weight percent composition.

C	0.3-0.6
Mn	3.0-4.5
Si	1.0-2.0
Cr	0.6-2.5
Ni	0.6-2.5
Mo+½W	Up to 0.5
Cu	0.3-1.0
Co	0.01 max.
V+$_{5/9}$Nb	0.1-0.5
Ti	0.025 max.
Al	0.025 max.
Ca	0.005 max.
N	0.02 max.

The balance is iron and the usual impurities, wherein the impurities include not more than about 0.03% phosphorus and not more than about 0.003% sulfur. The alloy is further defined by containing Si, Cu, V, and optionally Nb such that $2 \leq (\%Si + \%Cu)/(\%V+(5/9) \times \%Nb) \leq 34$.

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Description

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

[0001] This invention relates to a steel alloy having a unique combination of high strength, high toughness, and high ductility. The invention also relates to the use of the steel alloy to make thin gauge product forms such as strip and sheet that can be readily formed into parts for automotive use.

DESCRIPTION OF THE RELATED ART

[0002] The US Environmental Protection Agency requires that new cars must meet a 54.5 miles/gallon corporate average fuel economy standard by the year 2025. This requirement will likely cause automobile manufacturers to reduce the weights of their vehicles. Lightweight materials such as aluminum and composite materials that provide high strength and significant reduction in weight compared to the known steel alloys can be used for making thin-gauge auto body and frame parts. However, the use of such materials will present challenges to auto manufacturers because their production line-ups are designed for using steel alloys and a change to non-steel materials such as aluminum and composites would require substantial capital investments as well as a substantial increase in the cost of materials.

[0003] Steel sheet and strip that provide higher strength than conventional steels used for auto body and frame applications can be used to reduce the weight of stamped body and frame parts in this "Light Weighting" effort as long as they are sufficiently tough and formable. A measure of the strength and formability of a steel is a Strip Index Number (SIN) which is the product of the ultimate tensile strength (UTS) in MPa and the Elongation in %. For many automotive applications steel sheet and strip having an SIN of at least about 20,000 provide sufficient weight reduction while providing adequate strength and formability. However, for structural parts that require higher strength, an SIN of at least about 30,000 is preferred. Many of the steels known as advanced high strength steels (AHSS) leave something to be desired with respect to ductility because strength and ductility are inversely related properties. Good ductility is needed for strip and sheet forms of high strength steel material to provide good formability. Accordingly, it would be desirable to have a steel alloy that provides a combination of high strength and ductility that not only results in significant weight reduction in automotive body and frame parts, but also can be readily formed into such products.

SUMMARY OF THE INVENTION

[0004] The foregoing need is resolved to a large degree by a steel alloy in accordance with the present invention. The alloy according to this invention provides a unique combination of very high strength, toughness, and ductility. The alloy of this invention can be characterized by the broad, intermediate and preferred weight percent compositions set forth below.

Element	Broad	Intermediate	Preferred A	Preferred B
C	0.3-0.6	0.30-0.45	0.30-0.40	0.30-0.36
Mn	3.0-4.5	3.5-4.5	3.5-4.5	3.5-4.5
Si	1.0-2.0	1.3-1.8	1.3-1.7	1.3-1.7
Cr	0.6-2.5	0.75-2.35	1.6-2.35	0.75-1.5
Ni	0.6-5.0	0.7-4.5	3.7-4.3	0.7-2.5
Mo+½W	Up to 0.5	Up to 0.3	0.1 max.	0.15-0.25
Cu	0.3-1.0	0.4-0.7	0.4-0.6	0.4-0.6
Co	0.01 max.	0.01 max.	0.01 max.	0.01 max.
V+5/9Nb	0.1-0.5	0.2-0.4	0.30-0.40	0.20-0.30
Ti	0.025 max.	0.020 max.	0.020 max.	0.020 max.
Al	0.025 max.	0.020 max.	0.020 max.	0.020 max.
Ca	0.005 max.	0.002 max.	0.001 max.	0.001 max.
N	0.02 max.	0.02 max.	0.020 max.	0.020 max.

[0005] The balance of the alloy is iron and the usual impurities found in commercial grades of steel alloys produced for similar use and properties. Among said impurities phosphorus is preferably restricted to not more than about 0.03% max. and sulfur is preferably restricted to not more than about 0.003% max.

[0006] The foregoing tabulation is provided as a convenient summary and is not intended to restrict the lower and upper values of the ranges of the individual elements for use in combination with each other, or to restrict the ranges of the elements for use solely in combination with each other. Thus, one or more of the ranges can be used with one or more of the other ranges for the remaining elements. In addition, a minimum or maximum for an element of a broad or preferred composition can be used with the minimum or maximum for the same element in another preferred or intermediate composition. Moreover, the alloy according to the present invention may comprise, consist essentially of, or consist of the constituent elements described above and throughout this application. Here and throughout this specification the term "percent" or the symbol "%" means percent by weight or mass percent, unless otherwise specified. Furthermore, the term "about" used in connection with a weight percent value or range means the usual analytical tolerance or experimental error expected by a person skilled in the art based on known, standardized measuring techniques.

[0007] In accordance with another aspect of this invention, there is provided a thin gauge steel product such as sheet or strip product that is made from one of the steel alloys described in the table. The thin gauge products can be readily formed into automotive parts because of their good ductility. A thin gauge steel product in accordance with this aspect of the invention has an SIN of at least about 20,000 and better yet, and SIN of at least 25,000. A preferred embodiment of the steel product has an SIN of at least about 30,000.

DETAILED DESCRIPTION

[0008] The weight percent ranges described above can be further defined by the roles the elements play in the alloy of this invention. The combination of the elements silicon, copper, and vanadium, and niobium when present, function as diffusion modifiers for the purposes of this invention because they have been shown to reduce the diffusion of carbon as well as deleterious tramp elements such as P and S to the grain boundaries of the alloy. Within the foregoing weight percent ranges, silicon, copper, and vanadium, and niobium when present, are broadly balanced such that

$$2 \leq (\%Si + \%Cu)/(\%V+(5/9) \text{ x } \%Nb) \leq 34.$$

For strip applications where the SIN is required to be at least about 30,000, silicon, copper, and vanadium, and optionally niobium, are preferably balanced such that

$$4.5 \leq (\%Si + \%Cu)/(\%V+(5/9) \text{ x } \%Nb) \leq 10.$$

Molybdenum is optionally present in the alloy according to this invention and tungsten may be substituted for some or all of the molybdenum in this alloy. When present, tungsten is substituted for molybdenum on a 2:1 basis such that Mo+ ½W is about 0.20-0.5% and preferably about 0.15-0.3%. Yttrium and magnesium may also be present in this alloy either separately or in combination. In this regard the alloy may contain about 0.001-0.025% yttrium and preferably may contain about 0.002-0.020% yttrium. The alloy may also contain about 0.001-0.01% magnesium and preferably may contain about 0.001-0.006% magnesium. The magnesium and/or yttrium is added during primary melting to deoxidize the steel alloy. Magnesium and yttrium also benefit the strength and toughness of this steel by aiding in grain refinement of the alloy during processing.

[0009] The elements molybdenum, tungsten, and chromium combine with carbon to form M_2C carbides (where M is Cr, Mo, and/or W) during tempering. The elements Mo, W, and Cr can be referred to as tempered carbide formers for the purposes of the alloy according to this invention. Thus, chromium and molybdenum and tungsten when present, promote the formation of M_2C carbides and can be substituted for each other in this alloy. For thin gauge product forms such as strip and sheet where an SIN of at least 30,000 is desired, a positive addition of molybdenum and or tungsten is included as described above. Further, within the foregoing weight percent ranges, molybdenum, chromium, and carbon are preferably balanced such that $3.5 \leq (\%Mo + \% Cr)/(\%C) < 7.5$.

[0010] The elements manganese and nickel are austenite stabilizers and contribute to the good hardenability of this alloy. Manganese and nickel can be substituted for each other to a limited extent to stabilize austenite. For the thin gauge product applications where an SIN of at least about 30,000 is desired, within the foregoing weight percent ranges, manganese and nickel are broadly balanced such that $3.5 \leq (\%Mn + \%Ni) \leq 8.0$.

[0011] This alloy and products made therefrom are preferably prepared by vacuum melting techniques. In this regard, primary melting of the alloy is preferably accomplished with vacuum induction melting (VIM). When desired, as for more critical applications, the alloy can be refined using vacuum arc remelting (VAR). Primary melting may also be performed by arc melting in air (ARC) if desired. After ARC melting, the alloy may be refined by electroslag remelting (ESR) or VAR.

[0012] The alloy of this invention is preferably processed to thin gauge forms such as strip or sheet. In strip or sheet form, parts made from the alloy can be austenitized for short times at a temperature of about 1400 to 1900°F (760 and 1038°C) and then air cooled. The parts can then be used in service. Alternatively, annealed strip or sheet can be formed into a shaped part and then regions of the part can be selectively heat treated by induction heating to the austenitizing temperature of 1400 to 1900°F (760 and 1038°C) followed by cooling in air. Another option is to heat the strip or sheet material to the austenitizing temperature of 1400 to 1900°F (760 and 1038°C) then stamp the part to form it and allow the hot stamped part to air cool. The parts can be used in the air-cooled condition or after short time tempers at 400 to 700°F (204.4-371°C). The alloy has relatively high ultimate tensile strength (UTS) in the annealed condition, i.e., at least about 150 ksi (1025 MPa) on average, combined with very high ductility (i.e., 10-25% Elongation). Therefore, parts made from annealed alloy strip or sheet may be used in some applications without any further heat treatment.

[0013] The alloy may also be hot worked from a temperature of up to about 2100°F (1149°C), preferably at about 1800°F (982°C), to form various intermediate product forms such as billets and bars. The alloy is preferably heat treated by austenitizing at about 1585°F (863°C) to about 1835°F (1002°C) for about 1-2 hours. The alloy is then air cooled or oil quenched from the austenitizing temperature. When desired, the alloy can be vacuum heat treated and gas quenched. Parts made from the alloy in bar form are preferably deep chilled at either -100°F (-73.3°C) or -320°F (-196°C) for about 1-8 hours and then warmed in air. If lower strength is acceptable the refrigeration step may be eliminated for parts made from bar products. The alloy is preferably tempered at about 400°F to 600°F (204.4-316°C) for about 2-3 hours and then air cooled. The alloy may be tempered at up to 700°F (371°C) when an optimum combination of strength and toughness is not required.

[0014] In accordance with a further aspect of the present invention there is provided a shaped part made from a thin gauge product form of the alloy as described above. The shaped part is preferably embodied as a stamped body or frame part for an automobile. A thin gauge product in accordance with the present invention is a part or component made from sheet or strip having a thickness of at least about 0.0009 in. (0.0229 mm) and less than 0.25 in. (6.35 mm).

WORKING EXAMPLES

Example I

[0015] To demonstrate the unique combination of properties provided by the alloy according to the present invention, representative examples of the alloy and examples of comparative alloys were melted, processed, and tested. The weight percent compositions of the tested alloys are set forth in Table 1 below. Examples 1 and 2 represent the alloy according to the present invention. Alloys A and B are comparative alloys.

TABLE 1

Element	Example 1	Example 2	Alloy A	Alloy B
C	0.51	0.36	0.48	0.38
Mn	0.68	4.02	6.88	4.71
Si	1.45	1.44	1.43	1.70
Cr	1.98	1.98	1.99	1.60
Ni	6.85	3.96	0.70	3.88
Mo	---	---	---	0.12
Cu	0.64	0.52	0.64	0.66
V	0.22	0.36	0.21	0.30

The balance of each composition in Table 1 is iron and impurities.

[0016] The examples and comparative alloys were vacuum induction melted and cast as 35 lb. (15.9 kg) heats. The heats were hot worked and rough machined into sets of duplicate standard tensile specimens. The pairs of specimens from each set were austenitized at different temperatures for 1.5 hours and then oil quenched. The specimen pairs were then tempered for 2 hours and air cooled. The combinations of austenitizing temperature and tempering temperature used for the specimen pairs of each alloy are set forth in Table 2 below.

TABLE 2

Heat Treatment ID	Austenitizing Temperature	Tempering Temperature
A	1635°F	400°F
B	1635°F	600°F
C	1685°F	400°F
D	1685°F	500°F
E	1735°F	400°F

After heat treatment, the test specimens were finish machined to final dimension and tested. The results of room temperature tensile tests for each example are presented in Tables 3A to 3D below including the 0.2% offset yield strength (Y.S.), the ultimate tensile strength (U.T.S.), the percent elongation (% El.), and the percent reduction in area (%R.A.). Also included in the tables are calculations of the SIN for each specimen (SIN = UTS in MPa x % El.). Average values for each pair of the tested specimens are also presented in the tables.

TABLE 3A

			Y.S.		U.T.S.		%El.	%R.A.	SIN
Heat ID	Heat Treatment	Sample	ksi	MPa	ksi	MPa			
Example 1	**A**	A1	186.7	1287.5	300.7	2072.9	17.7	32.7	**36,691**
		A2	184.8	1274.2	301.6	2079.3	14.4	23.2	**29,942**
		Avg.	**185.8**	**1280.8**	**301.1**	**2076.1**	**16.1**	**27.9**	**33,317**
	B	B1	192.0	1323.7	255.7	1762.7	15.3	31.4	**26,969**
		B2	196.0	1351.5	256.7	1770.1	18.5	39.6	**32,747**
		Avg.	**194.0**	**1337.6**	**256.2**	**1766.4**	**16.9**	**35.5**	**29,858**
	C	C1	164.4	1133.4	304.5	2099.5	14.4	18.2	**30,233**
		C2	165.0	1137.4	304.0	2096.0	15.4	18.3	**32,278**
		Avg.	**164.7**	**1135.4**	**304.3**	**2097.7**	**14.9**	**18.3**	**31,255**
	D	D1	173.3	1194.8	274.1	1890.1	16.1	21.8	**30,431**
		D2	177.0	1220.3	274.5	1892.4	19.3	39.6	**36,524**
		Avg.	**175.1**	**1207.6**	**274.3**	**1891.3**	**17.7**	**30.7**	**33,477**
	E	E1	151.5	1044.4	304.0	2095.7	15.4	21.1	**32,273**
		E2	162.3	1119.2	304.3	2097.7	18.0	35.8	**37,759**
		Avg.	**156.9**	**1081.8**	**304.1**	**2096.7**	**16.7**	**28.5**	**35,016**

TABLE 3B

			Y.S.		U.T.S.		%EL.	%R.A.	SIN
Heat ID	Heat Treatment	Sample	ksi	MPa	(ksi)	MPa			
Example 2	**A**	A1	121.3	836.4	284.4	1960.9	15.8	19.0	**30,903**
		A2	125.3	863.6	285.0	1965.2	17.1	28.9	**33,546**
		Avg.	**123.3**	**850.0**	**284.7**	**1963.1**	**16.4**	**24.0**	**32,225**
	B	B1	139.6	962.5	240.8	1660.3	19.4	21.8	**32,211**
		B2	143.6	990.4	239.1	1648.8	21.4	18.3	**35,285**
		Avg.	**141.6**	**976.4**	**240.0**	**1654.6**	**20.4**	**20.0**	**33,748**
	C	C1	121.7	839.2	285.3	1966.7	15.7	23.9	**30,878**

(continued)

Heat ID	Heat Treatment	Sample	Y.S. ksi	Y.S. MPa	U.T.S. (ksi)	U.T.S. MPa	%EL.	%R.A.	SIN
		C2[1]							
		Avg.	**121.7**	**839.2**	**285.3**	**1966.7**	**15.7**	**23.9**	**30,878**
	D	D1	124.6	859.4	264.6	1824.1	17.3	25.4	**31,557**
		D2	128.9	888.5	263.1	1814.2	21.4	28.1	**38,824**
		Avg.	**126.8**	**874.0**	**263.8**	**1819.2**	**19.4**	**26.7**	**35,191**
E		E1	111.8	770.9	289.5	1996.2	13.7	13.2	**27,348**
		E2	115.2	794.0	289.3	1994.9	14.8	17.6	**29,525**
		Avg.	**113.5**	**782.5**	**289.4**	**1995.6**	**14.3**	**15.4**	**28,436**

[1] Sample not tested because of forging defect.

TABLE 3C

Heat ID	Heat Treatment	Sample	Y.S. ksi	Y.S. MPa	U.T.S. ksi	U.T.S. MPa	%El.	%R.A.	SIN
Alloy A	**A**	A1	61.9	426.7	100.6	693.7	8.8	8.6	**6,104**
		A2	60.8	418.9	115.7	797.5	9.5	8.5	**7,568**
		Avg.	**61.3**	**422.8**	**108.1**	**745.6**	**9.1**	**8.5**	**6,836**
	B	B1	67.0	461.8	132.2	911.6	9.7	8.0	**8,843**
		B2	65.2	449.4	154.9	1067.7	11.8	9.4	**12,598**
		Avg.	**66.1**	**455.6**	**143.5**	**989.6**	**10.8**	**8.7**	**10,721**
	C	C1	62.8	433.1	146.3	1008.5	11.6	11.5	**11,699**
		C2	63.0	434.1	132.3	912.4	12.1	11.5	**11,040**
		Avg.	**62.9**	**433.6**	**139.3**	**960.4**	**11.9**	**11.5**	**11,369**
	D	D1	65.0	448.4	140.0	965.5	12.5	10.7	**12,068**
		D2	62.9	433.5	127.6	879.7	10.1	10.8	**8.885**
		Avg.	**64.0**	**441.0**	**133.8**	**922.6**	**11.3**	**10.7**	**10,477**
	E	E1	59.6	411.1	132.8	915.5	12.0	12.4	**10,986**
		E2	57.3	395.1	117.4	809.7	10.7	11.5	**8,663**
		Avg.	**58.5**	**403.1**	**125.1**	**862.6**	**11.4**	**12.0**	**9,825**

TABLE 3D

Heat ID	Heat Treatment	Sample	Y.S. ksi	Y.S. MPa	U.T.S. ksi	U.T.S. MPa	%El.	%R.A.	SIN
Alloy B	**A**	A1	55.9	385.1	221.2	1525.2	6.7	6.5	**10,265**
		A2	64.5	444.6	212.4	1464.1	6.7	5.9	**9,853**
		Avg.	**60.2**	**414.8**	**216.8**	**1494.7**	**6.7**	**6.2**	**10,059**
	B	B1	91.7	632.2	220.5	1520.0	5.5	9.3	**8,360**
		B2	79.5	547.9	208.6	1438.4	5.8	13.2	**8,343**
		Avg.	**85.6**	**590.1**	**214.5**	**1479.2**	**5.7**	**11.2**	**8,351**
	C	C1	70.4	485.4	188.6	1300.4	4.9	4.1	**6,372**

(continued)

Heat ID	Heat Treatment	Sample	Y.S. ksi	Y.S. MPa	U.T.S. ksi	U.T.S. MPa	%El.	%R.A.	SIN
		C2	68.5	472.5	210.0	1447.8	5.5	4.0	**7,963**
		Avg.	**69.5**	**478.9**	**199.3**	**1374.1**	**5.2**	**4.1**	**7,168**
	D	D1	68.3	471.1	195.6	1348.3	5.5	4.9	**7,416**
		D2	66.9	461.5	219.3	1512.0	6.7	8.4	**10,130**
		Avg.	**67.6**	**466.3**	**207.4**	**1430.2**	**6.1**	**6.7**	**8,773**
	E	E1	53.2	366.9	162.1	1117.6	3.7	3.3	**4,135**
		E2	49.8	343.4	139.4	961.1	3.8	3.3	**3,652**
		Avg.	**51.5**	**355.2**	**150.7**	**1039.4**	**3.8**	3.3	**3,894**

Example II

[0017] In order to demonstrate that the alloy of the present invention is capable of providing the desired combination of properties when scaled up to commercial production-size heats, two additional heats were melted, processed, and tested. The weight percent compositions of the tested alloys are set forth in Table 4 below. Example 3 represents the alloy according to the Preferred A composition of the alloy according to the present invention and Example 4 represents the alloy according to the Preferred B composition of the alloy according to the present invention.

TABLE 4

Element	Example 3	Example 4
C	0.357	0.311
Mn	4.01	4.04
Si	1.54	1.57
P	0.018	0.015
S	<0.0005	<0.0005
Cr	2.05	1.11
Ni	4.02	0.96
Mo	0.03	0.20
Cu	0.51	0.51
V	0.36	0.24
Ti	0.0050	0.0040
Al	0.0020	0.0060
N	0.0044	0.0041
Ca	0.0015	0.0016

The balance of each composition in Table 4 is iron and impurities.

[0018] Examples 3 and 4 were melted and refined by ARC and AOD as 40-ton heats and then cast as billet on a continuous caster. The continuously cast billets were hot worked and rough machined into sets of duplicate standard tensile specimens. Duplicate tensile test specimens for Example 3 were prepared from 0.150 inch thick hot rolled band. Duplicate tensile test specimens for Example 4 were prepared from 0.150 inch thick hot rolled band as follows. A first set of specimens were prepared from the 0.150 in. band after grinding the band material to a final thickness of 0.110 in. A second set of specimens were prepared by cold rolling the 0.150 in. band material to form strip having a thickness of 0.130 in. The strip material was ground to a final thickness of 0.087 in. A third set of specimens were prepared by cold rolling the band material to form strip having a thickness of 0.110 in. and then grinding the strip material to a final thickness of 0.074 in.

[0019] The pairs of the tensile specimens of Example 3 were heat treated by placing the specimens into stainless steel bags which were then backfilled with argon gas and divided into subsets. Each subset was heat treated in accordance with one of the heat treatments A-H set forth in Table 2 above. Austenitizing was performed by holding the specimen subset at temperature for 1.5 hours and then oil quenching to room temperature. Tempering was performed by holding the specimen subset at the respective tempering temperature for 2 hours followed by air cooling to room temperature.

[0020] The pairs of tensile specimens of Example 4 were heat treated in three groups. One group was heat treated with Heat Treatment A in Table 2 above. A second group was heat treated with Heat Treatment C of Table 2 and the third group was heat treated with Heat Treatment E of Table 2. Austenitizing was performed by holding the specimens at the respective temperature for 1.5 hours and then air cooling to room temperature. Tempering was performed by holding the specimens at the respective tempering temperature for 2 hours followed by air cooling to room temperature.

[0021] The results of room temperature tensile tests for Example 3 are presented in Table 5 below including the 0.2% offset yield strength (Y.S.), the ultimate tensile strength (U.T.S.), the percent elongation (% El.), and the percent reduction in area (%R.A.). Also included in the tables are calculations of the SIN for each specimen (SIN = UTS in MPa x % El.). Average values for each pair of the tested specimens are also presented in the tables.

TABLE 5

			Y.S.		**U.T.S.**		**%El.**	**%R.A.**	**SIN**
Heat ID	**Heat Treatment**	**Sample**	**ksi**	MPa	**ksi**	MPa			
Example 3	**A**	A1	150.2	1035.5	267.9	1846.8	17.0	38.8	**31,395**
		A2	141.9	978.3	271.6	1872.6	18.0	21.3	**33,707**
		Avg.	**146.0**	**1006.9**	**269.7**	**1859.7**	**17.5**	**30.0**	**32,551**
	B	B1	161.2	111.2	230.7	1590.5	21.3	42.7	**33,877**
		B2	159.9	1102.5	228.9	1578.2	20.2	31.3	**31,879**
		Avg.	**160.5**	**1106.9**	**229.8**	**1584.6**	**20.8**	**37.0**	**32,878**
	C	C1	143.3	987.7	269.2	1856.4	17.9	31.3	**33,229**
		C2	139.7	963.0	267.7	1845.8	20.1	39.2	**37,101**
		Avg.	**141.5**	**975.4**	**268.5**	**1851.1**	**19.0**	**35.2**	**35,165**
	D	D1	146.6	1010.8	250.1	1724.4	20.6	36.6	**35,522**
		D2	156.5	1079.0	245.4	1691.8	20.0	39.1	**33,837**
		Avg.	**151.6**	**1044.9**	**247.7**	**1708.1**	**20.3**	**37.8**	**34,680**
	E	E1	141.9	978.6	265.6	1831.1	17.6	35.7	**32,264**
		E2	137.5	948.0	275.1	1896.8	*	36.7	**
		Avg.	**139.7**	**963.3**	**270.3**	**1864.0**	**17.6**	**36.2**	**32,264**
	F	**F1**	146.0	1006.5	243.0	1675.4	22.4	43.9	37,528
		F2	147.2	1014.8	245.0	1689.2	*	40.4	**
		Avg.	**146.6**	**1010.6**	**244.0**	**1682.3**	**22.4**	**42.2**	**37,528**
	G	**G1**	130.0	896.1	266.9	1840.5	17.9	29.1	32,945
		G2	131.1	904.0	268.5	1851.4	17.8	24.4	32,584
		Avg.	**130.5**	**900.0**	**267.7**	**1845.9**	**17.8**	**26.8**	**32,765**
	H	**H1**	137.3	946.7	262.4	1808.9	20.6	39.7	37,264
		H2	136.8	942.9	267.8	1846.4	*	32.9	**
		Avg.	**137.0**	**944.8**	**265.1**	**1827.7**	**20.6**	**36.3**	**37,264**

* = Invalid measurement - Specimen broke outside gage section
** = No value could be calculated.

[0022] The results of room temperature tensile tests for Example 4 are presented in Tables 6A, 6B, and 6C below.

TABLE 6A

			Y.S.		U.T.S.		%El.	%R.A.	SIN
Heat ID	**Heat Treatment**	**Sample**	**ksi**	MPa	**ksi**	MPa			
Example 4 Group 1	**A**	A1	174.0	1199.4	266.6	1837.9	*	*	**
		A2	173.9	1199.1	257.1	1772.3	13.9	41.3	**24,635**
		Avg.	**173.9**	**1199.2**	**261.8**	**1805.1**	**13.9**	**41.3**	**24,635**
	C	C1	164.8	1136.3	253.4	1746.9	14.0	32.7	**24,457**
		C2	169.0	1165.4	257.7	1776.9	14.6	23.2	**25,924**
		Avg.	**166.9**	**1150.8**	**255.5**	**1761.9**	**14.3**	**27.9**	**25,191**
	E	E1	164.4	1133.4	257.3	1774.0	13.1	39.5	**23,240**
		E2	172.5	1189.3	262.9	1812.6	13.0	35.5	**23,492**
		Avg.	**168.4**	**1161.4**	**260.1**	**1793.3**	**13.0**	**37.5**	**23,366**

* = Invalid measurement - Specimen broke outside gage section
** = No value could be calculated.

TABLE 6B

			Y.S.		U.T.S.		%El.	%R.A.	SIN
Heat ID	**Heat Treatment**	**Sample**	**ksi**	MPa	ksi	MPa			
Example 4 Group 2	**A**	A1	179.4	1237.2	262.3	1808.4	*	33.2	***
		A2	177.3	1222.4	253.3	1746.2	*	41.9	***
		Avg.	**178.4**	**1229.3**	**257.8**	**1777.3**		**37.5**	
	C	C1**							
		C2	175.1	1207.4	263.2	1814.6	*	43.2	***
		Avg.	**175.1**	**1207.4**	**263.2**	**1814.6**		**43.2**	
	E	E1	171.0	1178.7	266.3	1836.2	*	36.9	***
		E2	176.4	1215.9	265.2	1828.4	13.1	36.8	**23,934**
		Avg.	**173.7**	**1197.3**	**265.8**	**1832.3**	**13.1**	**36.8**	**23,934**

* = Invalid measurement - Specimen broke outside gage section.
** = No test because sample was damaged during processing.
*** = No value could be calculated.

TABLE 6C

			Y.S.		U.T.S.		%El.	%R.A.	SIN
Heat ID	**Heat Treatment**	**Sample**	ksi	MPa	**ksi**	MPa			
Example 4 Group 3	**A**	A1	191.5	1320.1	270.6	1865.6	*	40.7	**
		A2	185.1	1276.3	263.2	1814.6	11.9	43.1	**21,666**
		Avg.	**188.3**	**1298.2**	**266.9**	**1840.1**	**11.9**	**41.9**	**21,666**
	C	C1	167.8	1156.9	258.7	1783.8	12.8	46.5	**22,797**
		C2	171.4	1181.6	263.3	1815.1	11.6	17.3	**21,109**
		Avg.	**169.6**	**1169.2**	**261.0**	**1799.4**	**12.2**	**46.9**	**21,953**
	E	E1	171.1	1179.7	260.7	1797.1	12.6	44.5	**22,554**

(continued)

Heat ID	Heat Treatment	Sample	Y.S. ksi	Y.S. MPa	U.T.S. ksi	U.T.S. MPa	%El.	%R.A.	SIN
		E2	174.7	1204.2	260.5	1796.4	13.6	46.1	24,377
		Avg.	**172.9**	**1191.9**	**260.6**	**1796.8**	**13.1**	**45.3**	**23,465**

* = Invalid measurement - Specimen broke outside gage section
** = No value could be calculated.

[0023] The data presented in Tables 3A-3D, 5, and 6A-6C show that the preferred alloys according to the present invention provide a desirable combination of strength and ductility that makes them uniquely suitable for use in automotive parts made from thin gauge product forms such as strip and sheet. Although one of the specimens was too damaged to be tested and the elongation measurements for some of the specimens were not valid, considered as a whole the data show that the preferred embodiments of the alloy of this invention provide the combination of properties for which the alloy was designed. The unique combination of very high strength and higher than expected ductility, provides a novel solution to the automotive industry for making shaped body and frame parts with reduced weight without sacrificing strength and toughness.

Claims

1. A steel alloy that provides a unique combination of strength, toughness, and ductility, said alloy consisting essentially of, in weight percent

C	0.3-0.6
Mn	3.0-4.5
Si	1.0-2.0
Cr	0.6-2.5
Ni	0.6-5.0
Mo+½W	Up to 0.5
Cu	0.3-1.0
Co	0.01 max.
V+5/9Nb	0.1-0.5
Ti	0.025 max.
Al	0.025 max.
Ca	0.005 max.
N	0.02 max.

and the balance is iron and the usual impurities, wherein said impurities include not more than about 0.03% phosphorus and not more than about 0.003% sulfur; and wherein the elements Si, Cu, V, and Nb are balanced such that

$$2 \leq (\%Si + \%Cu)/(\%V+(5/9) \times \%Nb) \leq 34.$$

2. The alloy as claimed in Claim 1 which consists essentially of, in weight percent

C	0.30-0.45
Mn	3.5-4.5
Si	1.3-1.8
Cr	0.75-2.35
Ni	0.7-4.5
Mo+½W	Up to 0.3
Cu	0.4-0.7
Co	0.01 max.

(continued)

V+5/9Nb	0.2-0.4
Ti	0.020 max.
Al	0.020 max.
Ca	0.002 max.
N	0.02 max.

and wherein the elements Si, Cu, V, and Nb are balanced such that

$$4.5 \leq (\%Si + \%Cu)/(\%V+(5/9) \text{ x } \%Nb) \leq 10.$$

3. The alloy as claimed in Claim 1 which consists essentially of, in weight percent

C	0.30-0.40
Mn	3.5-4.5
Si	1.3-1.7
Cr	1.6-2.35
Ni	3.7-4.3
Mo+½W	0.1 max.
Cu	0.4-0.6
Co	0.01 max.
V+5/9Nb	0.30-0.40
Ti	0.020 max.
Al	0.020 max.
Ca	0.002 max.
N	0.02 max.

and wherein the impurities include not more than about 0.025% phosphorus and not more than about 0.0025% sulfur, the elements Si, Cu, V, and Nb are balanced such that

$$\text{(a)}\ \ 4.5 \leq (\%Si + \%Cu)/(\%V+(5/9) \text{ x } \%Nb) \leq 10;$$

the elements Mo, Cr, and C are balanced such that

$$\text{(b)}\ \ 4.25 \leq (\%Mo + \% Cr)/(\%C) \leq 7.5;$$

and
the elements Mn and Ni are balanced such that

$$\text{(c)}\ \ 3.5 \leq \%Mn+\%Ni \leq 8.0.$$

4. The alloy as claimed in Claim 1 which consists essentially of, in weight percent

C	0.30-0.36
Mn	3.5-4.5
Si	1.3-1.7
Cr	0.75-1.5
Ni	0.7-2.5
Mo+½W	0.15-0.25

(continued)

Cu	0.4-0.6
Co	0.01 max.
V+5/9Nb	0.20-0.30
Ti	0.020 max.
Al	0.020 max.
Ca	0.002 max.
N	0.02 max.

and wherein the impurities include not more than about 0.025% phosphorus and not more than about 0.0025% sulfur.

5. The alloy as claimed in any one of the preceding claims wherein (Mo+ ½W) is at least about 0.20%.

6. The alloy as claimed in any of Claims 1, 2, 4, and 5 wherein the elements Mo, Cr, and C are balanced such that $3.5 \leq (\%Mo + \% Cr)/(\%C) < 7.5$.

7. The alloy as claimed in any one of Claims 1, 2, 4, 5, and 6 wherein the elements Mn and Ni are balanced such that $3.5 \leq \%Mn+\%Ni \leq 8$.

8. The alloy as claimed in any one of Claims 1, 2, 4, 5, and 6 wherein the elements Si, Cu V, and Nb are balanced such that

$$4.5 \leq (\%Si + \%Cu)/(\%V+(5/9) \text{ x } \%Nb) \leq 10.$$

9. The alloy as claimed in any one of the preceding claims which also contains 0.001-0.025% yttrium.

10. The alloy as claimed in any of the preceding claims which also contains 0.001-0.01% magnesium.

11. A thin gauge article made from the alloy claimed in any of the preceding claims.

12. A shaped part made from the thin gauge article claimed in Claim 11.