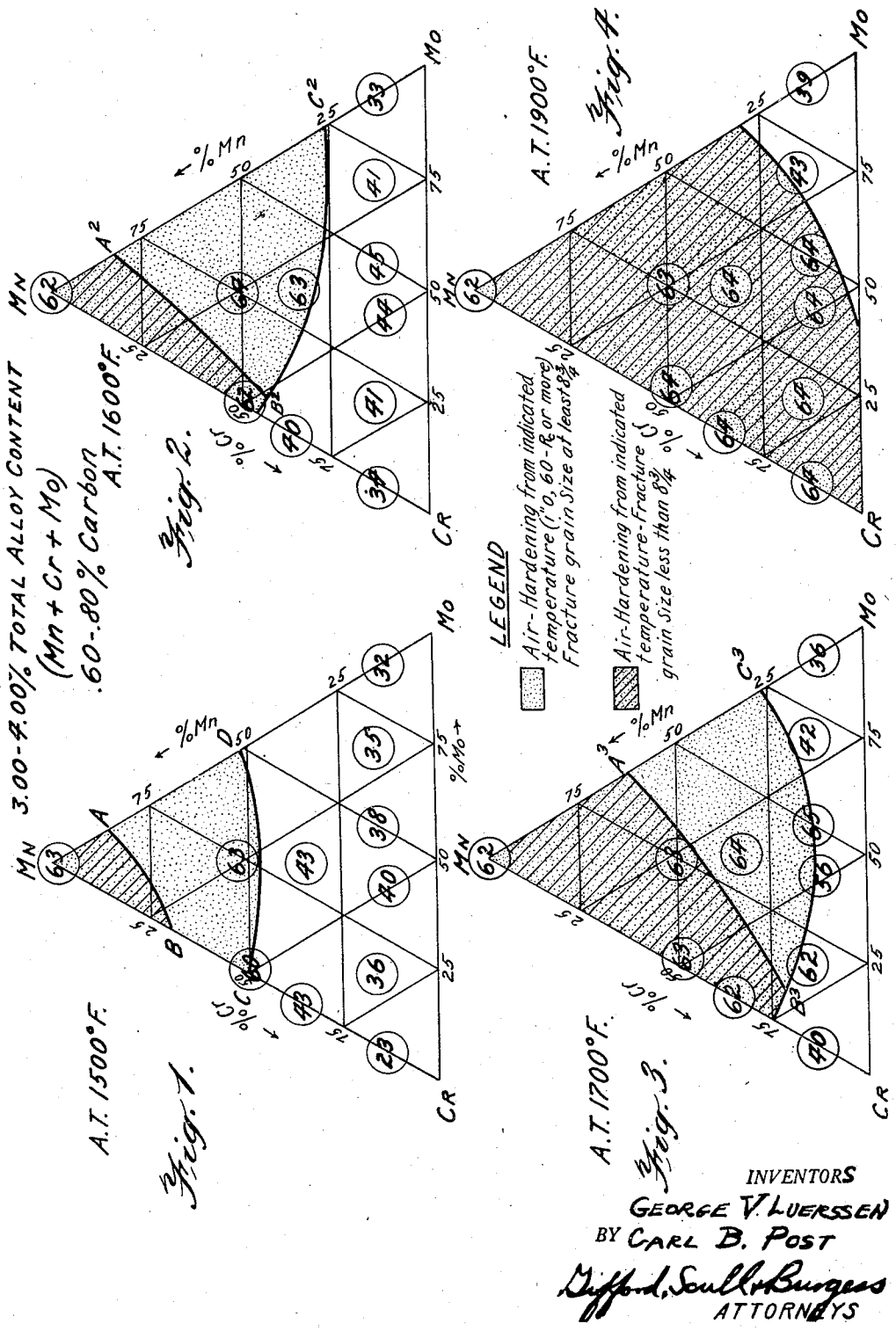
Aug. 8, 1944. G. V. LUERSSEN ET AL 2,355,224

STEEL ALLOY

Filed April 29, 1942 5 Sheets-Sheet 1

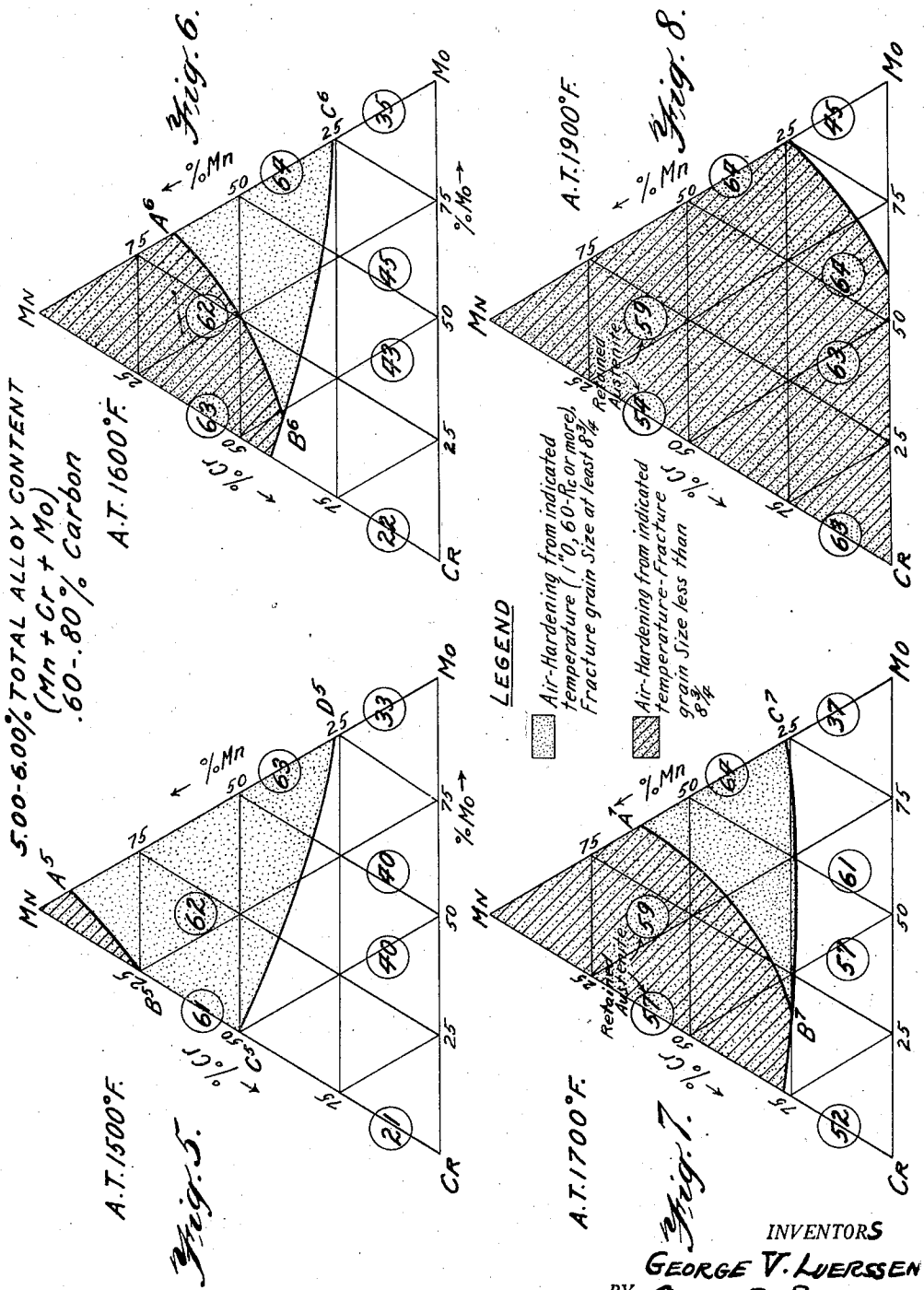


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STEEL ALLOY

Filed April 29, 1942 5 Sheets-Sheet 2

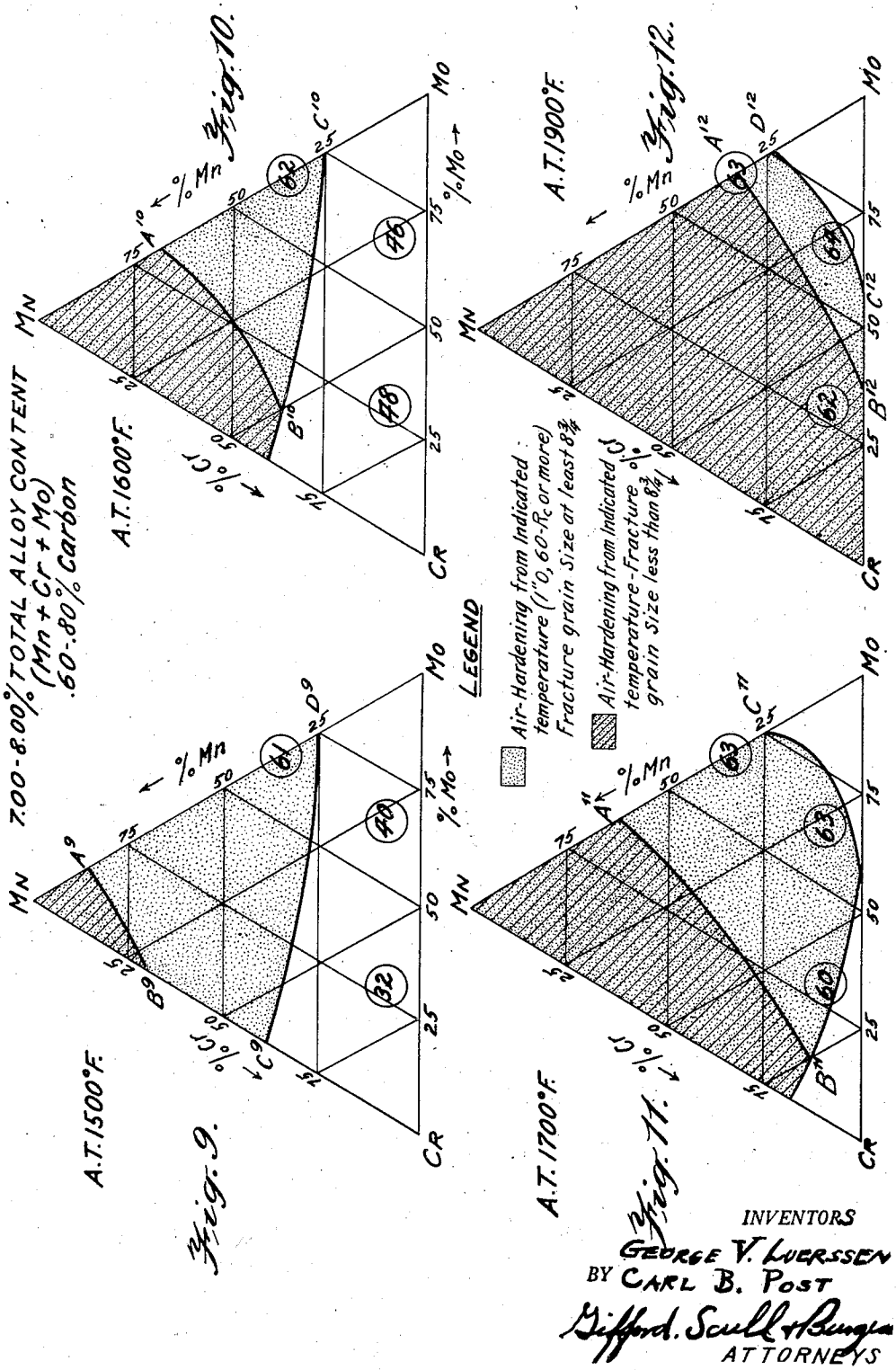


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Filed April 29, 1942 5 Sheets-Sheet 3



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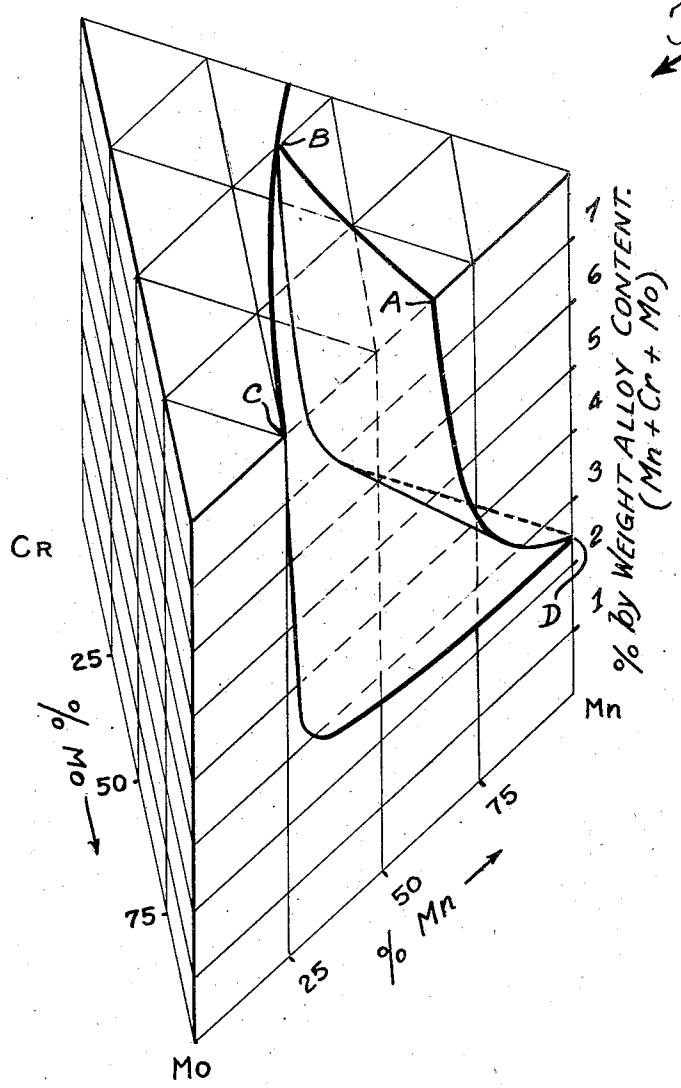
Aug. 8, 1944. G. V. LUERSSEN ET AL 2,355,224

STEEL ALLOY

Filed April 29, 1942 5 Sheets-Sheet 4

Fig. 13.

Fig. 14.



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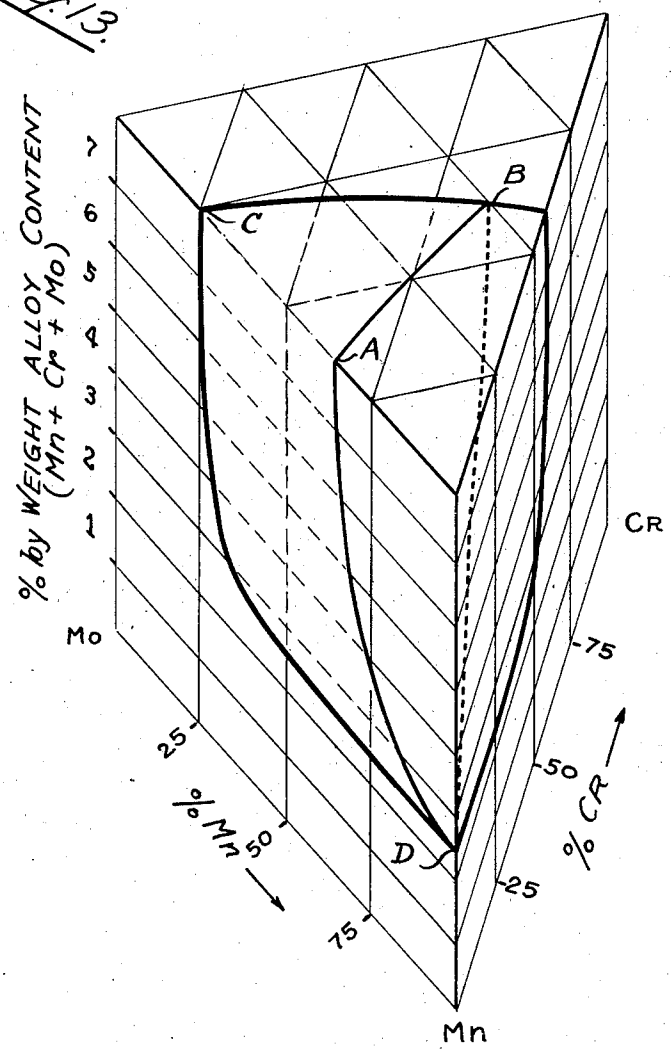
Aug. 8, 1944. G. V. LUERSSEN ET AL 2,355,224

STEEL ALLOY

Filed April 29, 1942 5 Sheets-Sheet 5

Fig. 14.

Fig. 13.



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STEEL ALLOY

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Application April 29, 1942, Serial No. 441,018

4 Claims. (Cl. 75—126)

This invention relates to an improvement in air-hardening steels of that class which contains manganese, chromium, and molybdenum. An object of this invention is to improve this kind of steel alloy so that large sections may be air hardened throughout from a relatively low heat treating temperature. It is also an object to reduce the amount of alloying material which it is necessary to use and yet obtain the advantageous results for which this alloying material has been used in the past.

With ordinary carbon steels, it is necessary to cool rapidly from a heat-treating temperature through the critical temperature range in order to produce certain hardening characteristics. This so-called "cooling" or "quenching," when carried out rapidly, brings with it some grave disadvantages, such as the setting up of undesirable internal stresses, cracks, distortions, and the like. In order to avoid these difficulties, certain elements, such as manganese, chromium, and molybdenum, have been introduced into the steel to enable it to be cooled more or less slowly in air and yet maintain its hardness. Air cooling, which is considered a slow form of cooling as distinguished from quenching in oil or water, permits the piece of steel to adjust itself internally and externally during the cooling operation so as not to set up any undesirable stresses which might cause cracking or distortion.

The prior art has recognized these advantages of air-hardening steels and certain analyses are known which show these desirable properties. With the analyses as known to the prior art, however, resort must be had to high treating temperatures in order to harden sections larger than 4" round x 4" long. When any steel is hardened from high temperatures two serious defects arise; (1) the steel is subject to severe scaling on the surface which leads to decarburization, and (2), grain growth is encountered if the steel is allowed to go slightly over its normal treating temperature. The first defect, generally leads to extra grinding and preparation costs in the fabrication of dies, etc., while the second will lead to "brittle" dies and tools as compared to those steels which are fine grained after heat treatment.

The following examples are given to illustrate the limitations of the prior art air hardening steels.

In sections approximately 1" round x 2" long, the following steel can be air-hardened from a temperature of about 1550°/1600° F.

Carbon	Manganese	Chromium	Molybdenum
Percent 1.00	*Percent* 2.00	*Percent* .75	*Percent* .75

However, in sections larger than 1" round x 2" long, this steel cannot be air hardened from any temperature below 1800° F., if at all, to give a Rockwell hardness of C–59 or more throughout the section.

In sections larger than 2" round x 3" to 4" long, steels of the following analyses can be air-hardened from temperatures of 1550°/1650° F. and will yield a Rockwell hardness equal to or greater than C–59:

Carbon	Manganese	Chromium	Molybdenum	Air treating temperature
Percent	*Percent*	*Percent*	*Percent*	°F.
1.00	2.00	1.00	1.00	1,600/1,650
1.00	2.00	2.00	1.00	1,550/1,600

These steels, however, cannot be air hardened to a Rockwell hardness of C–59 or more in sections larger than 2" round x 3" or 4" long, unless temperatures in the neighborhood of 1700°/1800° F. are used. Sections 4" round x 4" long of these steels must be air treated from temperatures in the neighborhood of 1700°/1800° F. in order to obtain a Rockwell hardness of C–59 or greater throughout the section.

In order to obtain air-hardening properties in sections approximately 6" round x 6" long, the prior metallurgical art has resorted to increased chromium contents, which in turn lead to higher heat treating temperatures. This is illustrated by the following analysis which shows a steel which will air-harden in sections approximately 6" round x 6" long from the temperatures indicated:

Carbon	Manganese	Chromium	Molybdenum	Air treating temperature
Percent	*Percent*	*Percent*	*Percent*	°F.
1.00	1.00	5.00	1.00	1,750/1,850

Steel of this analysis will not harden from any feasible tool treating temperature to a Rockwell hardness of C–59 or greater in sections larger than 6" round x 6" long.

We have discovered that by lowering the carbon content from the accepted 1% in these manganese-chromium-molybdenum steels, there is a marked increase in hardness penetration in sizes of sections ranging from 1" square to 10" round x 10" long and that if the alloying constituents are properly proportioned, such penetration can be obtained by hardening from relatively low temperatures, not exceeding 1600° F., with a saving of alloying content and with an advantageous fractured grain size.

The prior metallurgical art has recognized certain advantages to be associated with grain size of steel as displayed by the fracture appearance. Fracture grain size is represented by an arbitrary

scale numbered 1 to 10 with the grain becoming finer as the fracture number increases. A set of fractures comprising ten steps representing these gradations from coarse to fine grained steels is commonly known as "Shepherd standard fractures." In the case of tool steels it is highly desirable to manufacture a steel with the finest grain size possible when treated from the normal hardening temperature of the steel. A fine grained fracture is generally one which corresponds to the Shepherd classification of 8 to 10, while a fracture number of 7 or less is generally classed as a coarse grain size.

We have found that, in an alloy containing 2.00% manganese, 1.00% chromium, and 1.00% molybdenum, if the carbon content is kept down between .60% and .80%, a 4" round x 4" long section can be air-treated from a temperature of 1525°–1550° F. to yield an inside Rockwell hardness of C–59 or greater, while a section of the same size treated at the same heat treating temperature but with 1.00% carbon, has an inside Rockwell of only about C–50.

In this alloy containing 2.00% manganese, 1.00% chromium and 1.00% molybdenum, if the carbon content is kept between .70% and .80%, a section 6" round x 6" long can be air treated from a temperature of 1575° F. to yield an inside Rockwell hardness of C–63/64, while a section of the same size, treated at the same heat treating temperature, but with .96% carbon would have an inside Rockwell hardness of only C–55. We have also found that in an alloy containing 3.00% manganese, 2.50% chromium and 2.50% molybdenum, if the carbon content is kept between .60% and .80%, a section 10" round x 10" long can be air treated from a temperature of 1550°/1600° F. to yield an inside Rockwell hardness of C–63, while a section of the same size, treated at the same heat treating temperature, but with 1.00% carbon had an inside Rockwell hardness of only C–57.

These tests indicate that an alloy containing approximately .60% to .80% carbon, 2.00%/3.00% manganese, 1.00%/2.50% chromium and 1.00%/2.50% molybdenum can be air treated in sections larger than 6" round x 6" long at temperatures of 1550°/1600° F. to yield inside Rockwell hardnesses of C–59 or greater, whereas the same alloys and same sections with 1.00% carbon must be air treated from temperatures of approximately 1800° F. to yield an inside Rockwell hardness of C–59 or greater. However, it can be demonstrated that grain coarsening will be encountered in the alloys containing 1.00% carbon when air treating temperatures of approximately 1800° F. are used, and this makes the use of these high air treating temperatures very undesirable.

As a general rule it can be said that the higher the alloy content of steel the slower will be its critical cooling velocity, i. e., the rate at which it must be cooled past its critical temperature range in order to obtain a completely hardened structure. Thus, if hardness penetration in large rounds were the only property desired in an alloy steel, it would suffice merely to increase the alloy content. If the total alloy content were increased in this manner, probably any desired depth of penetration could be obtained in any size section, but this higher alloy content would immediately necessitate air treating from much higher treating temperatures, or would increase quite markedly the annealing difficulties. Either of these results would be detrimental, because it would be necessary that the steel be annealed soft enough for commercial machine work, and the disadvantages of high treating temperatures has already been pointed out (warpage, excessive scaling, necessity for specially built high temperature furnaces, grain growth, etc.) In addition, these higher alloy contents would increase the cost of the steel considerably. These remarks emphasize the necessity for balancing the alloy content of deep air-hardening steels in such a manner that the alloy can be annealed without difficulty and also be capable of air-hardening in these large sections from low treating temperatures.

Using manganese - chromium - molybdenum steels with a carbon content of approximately .70%, we have determined the necessary proportions of manganese, chromium, and molybdenum to give an air hardening steel capable of being air treated from a temperature of not more than 1600° F. to yield an inside Rockwell hardness of C–60 or more at the center of large sections, i. e., sections 4" round x 4" long or larger. In order to do this, we have made a number of specimens with carbon contents nearly constant at .70–.75%, with the manganese content ranging from .50–3.00%, chromium nil to 5.00%, and molybdenum from nil to 5.00%. A melting series was devised so that various proportions of manganese, chromium, and molybdenum would coexist with one another in the different specimens. The various specimens were air-treated from 1500° F. to 1900° F. in steps of 100° F. After air cooling to room temperature, Rockwell hardnesses were obtained on freshly ground surfaces of the specimens and those which air-hardened were subsequently fractured and inside Rockwell hardnesses obtained.

The figures of the appended drawings show graphically the effect in a .60–.80% carbon steel of varying proportions of manganese, chromium, and molybdenum on the air-hardening properties.

Fig. 1 is a pseudo-ternary diagram of .60%–.80% carbon steels with a total alloy content of 3.00–4.00%, when air-hardened from 1500° F. The diagram shows a stippled area wherein the fracture grain size is at least 8¾ and an area both stippled and cross-hatched wherein it is less than 8¾. The Rockwell hardness is indicated by the figures in circles, and the position of each circle shows the proportions of alloying constituents for the indicated Rockwell hardness.

Figs. 2, 3, and 4 are similar to Fig. 1 but for hardening temperatures from 1600° F., 1700° F., and 1900° F., respectively.

Figs. 5, 6, 7, and 8 are similar to Figs. 1, 2, 3, and 4, except that these diagrams are for .60–.80% carbon steels having a total alloy content of 5.00–6.00%.

Figs. 9, 10, 11, and 12 are similar to Figs. 1, 2, 3, and 4, except that these diagrams are for .60–80% carbon steels having a total alloy content of 7.00–8.00%.

Fig. 13 is a three-dimensional diagram showing the relationship between manganese, chromium, and molybdenum, and the total alloy content, and corresponding to Figs. 2, 6, and 10, said Figs. 2, 6, and 10 being horizontal sections of Fig. 13, showing specific areas of manganese, chromium, molybdenum relationships for total alloy contents of 3% to 4%, 5% to 6%, and 7% to 8%, respectively.

The relative proportions of each alloying element to the total per cent by weight of the three alloying elements are set forth in each diagram.

For example, if the alloy being considered is composed of 2.00% Mn, 2.00% Cr, and 1.00% Mo, then the relative proportions of manganese, chromium, and molybdenum in this alloy containing a 5.00% total alloy are 40%, 40%, and 20%, respectively. For an alloy containing 3.00% Mn, 4.00% Cr, and 3.00% Mo, the relative proportions of manganese, chromium, and molybdenum in this 10% total alloy content analysis is considered to be 30%, 40%, and 30%, respecspectively. Using this system of presentation of inside Rockwell hardnesses obtained at various air-treating temperatures for these various alloys, the relative proportions of manganese, chromium, and molybdenum is represented in these ternary diagrams whose vertical axes represent the total alloy content in percent by weight.

The circles shown inside the ternary diagrams indicate the relative proportions of manganese, chromium, and molybdenum by weight, and the figures inside the circles refer to the Rockwell C hardnesses obtained at the air-treating temperatures referred to for each figure.

The stippled areas represent air-hardening alloys of a Rockwell hardness in excess of C–59 and a fracture grain size of at least 8¾. The areas which are both stippled and cross-hatched represent air-hardening alloys of a Rockwell hardness in excess of C–59 but a grain size of less than 8¾. The alloys with the most desirable characteristics are represented by the stippled areas.

While these diagrams represent the results obtained on specimens 1" square x 3" long, they indicate the results to be expected in large sections.

From our tests and experiments, the following general conclusions can be drawn in regard to desirable proportions of the alloying elements in manganese-chromium-molybdenum steels having about .70% carbon:

In a steel with a total alloy content by weight of 2.50%, the manganese should be equal to or greater than nine times the chromium content and equal to or greater than the molybdenum content.

In a steel having a total alloy content by weight of 3.00–4.00%, the manganese should be equal to or greater than the chromium content and equal to or greater than one-third of the molybdenum content.

In a steel with a total alloy content by weight of 5.00–6.00%, the manganese should be equal to or greater than two-thirds of the chromium content and equal to or greater than one-third of the molybdenum content.

In a steel having a total alloy content by weight of 7.00–8.00%, the manganese should be equal to or greater than one-third of the chromium content and equal to or greater than one-fourth of the molybdenum content.

In a steel having a total alloy content by weight of 10.00%, the manganese should be equal to or greater than one-third of the chromium content and equal to or greater than one-fifth of the molybdenum content.

While we have shown the invention as embodied in a specific form, it is to be understood that various changes in details may be made without departing from the scope of the invention as defined by the appended claims.

We claim:

1. A deep air hardening steel capable of being air hardened in sections at least as large as those typified by sections 4 inches round x 4 inches long, from temperatures not higher than about 1600 degrees Fahrenheit, to give a Rockwell C (R_c) hardness of at least about 60 and a fracture grain size of at least about 8, and capable of being annealed to a condition sufficiently soft for commercial machining requirements, said steel having a carbon content of about 0.60 to 0.80 per cent., a total alloy content of about 3 to about 8 per cent. and the balance principally iron, and in which steel the relationship between the alloying elements, manganese, chromium, and molybdenum and the total alloy content is that defined by the volume A, B, C, D, delineated in Figs. 13 and 14, and the areas A^2, B^2, C^2, A^6, B^6, C^6, and A^{10}, B^{10}, C^{10} of Figs. 2, 6, and 10, respectively.

2. A deep air hardening steel capable of being air hardened in sections at least as large as those typified by sections 4 inches round x 4 inches long, from temperatures no higher than about 1600 degrees Fahrenheit, to give a Rockwell C (R_c) hardness of at least about 60 and a fracture grain size of at least about 8, and capable of being annealed to a condition sufficiently soft for commercial machining requirements, said steel having a carbon content of about 0.60 to 0.80 per cent., a total alloy content of about 3 to 4 per cent. and the balance principally iron, and in which steel the relationship between the alloying elements, manganese, chromium, and molybdenum is that defined by the area A^2, B^2, C^2 of Fig. 2.

3. A deep air hardening steel capable of being air hardened in sections at least as large as those typified by sections 4 inches round x 4 inches long, from temperatures no higher than about 1600 degrees Fahrenheit, to give a Rockwell C (R_c) hardness of at least about 60 and a fracture grain size of at least about 8, and capable of being annealed to a condition sufficiently soft for commercial machining requirements, said steel having a carbon content of about 0.60 to 0.80 per cent., a total alloy content of about 5 to 6 per cent. and the balance principally iron, and in which steel the relationship between the alloying elements, manganese, chromium, and molybdenum is that defined by the area A^6, B^6, C^6 of Fig. 6.

4. A deep air hardening steel capable of being air hardened in sections at least as large as those typified by sections 4 inches round x 4 inches long, from temperatures no higher than about 1600 degrees Fahrenheit, to give a Rockwell C (R_c) hardness of at least about 60 and a fracture grain size of at least about 8, and capable of being annealed to a condition sufficiently soft for commercial machining requirements, said steel having a carbon content of about 0.60 to 0.80 per cent., a total alloying content of about 7 to about 8 per cent. and the balance principally iron, and in which steel the relationship between the alloying elements, manganese, chromium, and molybdenum is that defined by the area A^{10}, B^{10}, C^{10} of Fig. 10.

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