

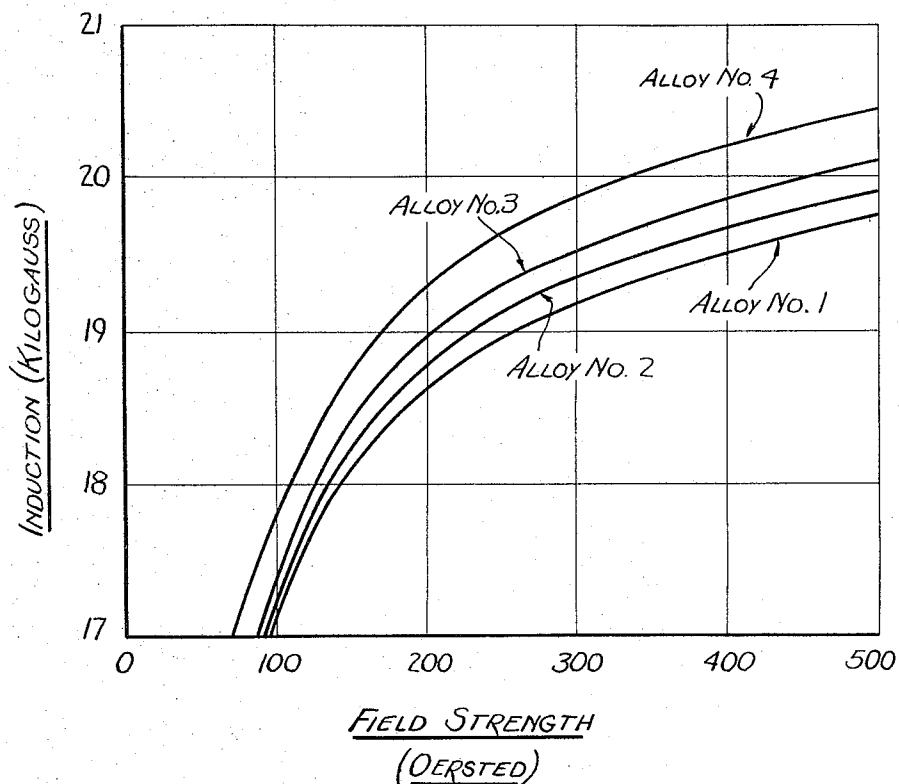
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ALLOY STEELS AND ARTICLES MADE THEREOF

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ALLOY STEELS AND ARTICLES MADE THEREOF
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The present invention relates to alloy steels and, more particularly, to low alloy steels characterized by special properties and adapted for large forgings in the manufacture of rotors, e.g., generator rotor shafts.

As is well known to those skilled in the art, the characteristics and properties of an alloy steel generally govern the use of the steel for commercial application. For example, forgings for generator shafts require a steel possessing relatively high tensile and yield strengths, low impact transition temperatures and good magnetic properties. The absence of one or more of these properties would preclude the use of a particular steel for such application. In addition to having good mechanical and physical properties, it would be most desirable that a steel for large forgings, particularly low alloy steels for large generator rotors, be capable of being stress-relieved in commercial operation at temperatures in the neighborhood of 600° C. (1112° F.) or above after heat treatment and machining without exceeding the A_{e1} temperature.

The stress-relieving treatment is a most important and fundamental consideration especially when viewed in the light of the fact that forgings up to 60-80 inches in diameter and weighing over 250,000 pounds are being produced commercially for generator rotors. As can be appreciated, accidental error in stress-relieving such forgings can bring about rather severe consequences. If the A_{e1} temperature is exceeded, the mechanical properties may be impaired and there may be some loss of magnetic permeability due to formation of untempered hard transformation products, for example, martensite, or retention of austenite which is non-magnetic. Impact properties also could be adversely affected. At lower temperatures, it is difficult to achieve an adequate degree of stress-relief in a reasonable heating time. Therefore, rather close furnace control has been a general prerequisite. Further, large forgings, e.g., generator rotor forgings, while they should be tempered at 600° C. or above, should be capable of being tempered at a temperature of at least 50° C., preferably 75° C., below the A_{e1} temperature for the alloy. From the commercial aspect this provides an important safety factor to the alloy because (1) considerable segregation may occur such that even after forging the A_{e1} temperature of the forging may vary from point to point and (2) it is possible to compensate for the difficulty in controlling tempering temperature accurately throughout forgings of large section.

The difficulty, however, is not simply one of providing alloy steels having high A_{e1} temperatures. There are many alloy steels having A_{e1} temperatures of the order of 650° C. (about 1200° F.) or higher but their mechanical and/or physical properties are such as to wholly preclude their use as steel forgings for many applications, e.g., forgings for generator rotor shafts.

It has now been discovered that certain low alloy steels containing correlated and special amounts of carbon, manganese, nickel, cobalt, molybdenum and chromium can be provided such that not only can large forgings thereof be readily stress-relieved at temperatures at least as high as 600° C. (1112° F.) and higher, e.g., 625° C. (1157° F.), but the forgings can be stress-relieved at such tempera-

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tures while providing a highly satisfactory combination of properties including high tensile and yield strengths, low impact transition temperatures, good impact strength and good magnetic properties.

It is an object of the present invention to provide low alloy steels characterized by a combination of mechanical and other properties which render the steels suitable for use in diversified applications.

Another object of the invention is to provide low alloy steels suitable for use as forgings in the manufacture of, inter alia, rotors, the steels being characterized by high tensile and yield strengths, low impact transition temperatures, good impact properties and good magnetic properties.

The invention also contemplates providing low alloy steels particularly adaptable for use as large forgings in the manufacture of rotor shafts and which combine the ability to be stress-relieved at temperatures at least as high as 600° C., e.g., 625° C., with a satisfactory combination of mechanical and other properties.

It is a further object of the invention to provide a process for accomplishing the foregoing.

Other objects and advantages will become apparent from the following description taken in conjunction with the accompanying drawing in which there is depicted a relationship between magnetic induction and field strength of certain alloy steels.

Generally speaking, the present invention contemplates providing low alloy steels suitable for use as large size forgings, e.g., forgings up to 40 inches in diameter and above, which can be stress-relieved at least as high as 600° C., e.g., 625° C., and which afford a highly satisfactory combination of properties including high tensile and yield strength, low impact transition temperatures and good impact strength. These characteristics render the alloy steels very satisfactory for turbine rotors, and the fact that the alloy steels possess good magnetic properties renders them especially suitable for use in the production of generator rotors. In accordance with the invention, the steels contain from 0.1% to 0.5% carbon, from 0.2% to 1% manganese, from 3.5% to 5.5% nickel, from 1.5% to 10% cobalt, from 0.2%, and preferably from 0.25%, to 0.5% molybdenum, from 0% to 0.5% vanadium, from 0% to 0.5% silicon and from 1% to 2% chromium, the balance being substantially all iron. By the phrase "balance substantially all iron" we do not exclude the presence of impurities or of other elements commonly present as incidental elements, e.g., deoxidizing and cleaning elements, and which do not adversely affect the novel and basic characteristics of the alloy steels. For example, up to 0.1% aluminum can be present as a residual deoxidizer.

The A_{e1} temperature of the steels according to the invention is sufficiently high to permit tempering or stress-relieving at a temperature of not less than 600° C. without causing impairment of the mechanical or magnetic properties.

At nickel contents below 3.5%, the hardenability, strength and impact resistance of the steels fall off while if more than 5.5% nickel is present, the magnetic properties are impaired. The preferred and most advantageous nickel content is from 4% to 4.5%.

Chromium in addition to nickel improves the hardenability of the steels and lowers the impact-transition temperature. On the other hand, high chromium contents to some extent impair the magnetic properties and it is accordingly advantageous that the chromium content not exceed 1.5%.

Cobalt has an important effect in improving the magnetic properties of the steels since it raises the magnetic induction in the range of field strength from 100 to 500

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oersteds used in large generator rotors. At cobalt contents below 1.5%, this effect is slight and preferably the cobalt content is at least 2% and most advantageously is at least 3%. Cobalt tends to reduce the hardenability of the steel so that cobalt content preferably does not exceed 5%.

The manganese and silicon contents preferably do not exceed 0.6% and 0.4%, respectively, and the carbon content is preferably from 0.2% to 0.3%. If manganese and silicon are added as deoxidants, the presence of some vanadium, e.g., at least 0.02%, is desirable as a grain-refiner. Preferably, the vanadium content does not exceed 0.2%.

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the cooling at the center of a 40 inch diameter air-cooled generator rotor. The bars were then either tempered at 600° C. for 24 hours followed by air-cooling to room temperature (Heat Treatment I) or tempered at 600° C. for 48 hours, air-cooled to room temperature, again tempered at 600° C. for 48 hours, and again air-cooled to room temperature (Heat Treatment II). All the melts were deoxidized with 0.05% aluminum.

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The heat treatment and the mechanical properties of the steels are shown in Table II and the magnetic properties, to wit, the number of ampere-turns per inch required to induce a flux density of 130 kilolines per square inch, are given in Table III:

TABLE II

Steel No.	Heat Treatment	L.P., t.s.i.	0.1% P.S., t.s.i.	U.T.S., t.s.i.	Elongation (percent) 4√area	R.A. (percent)	Room Temp. Impact Value, ft.-lb.	Impact Transition Temp. ¹ (° C.)
1-----	I	25.4	37.2	52.4	20.2	59.2	84	-66
1-----	II	32.2	37.5	48.0	29.2	71.4	87	-64
2-----	I	30.4	42.3	55.8	27.0	67.4	88.5	-86
2-----	II	35.7	40.2	50.3	33.7	68.4	70.5	-19
3-----	I	33.0	43.4	56.5	27.0	64.6	59.5	-3
3-----	II	35.7	40.0	50.8	34.9	67.0	63	+3
4-----	I	37.5	46.5	56.3	29.2	67.4	81.5	-13
4-----	II	39.3	41.1	52.0	30.4	67.8	70.5	-9

L.P.=Limit of proportionality.
t.s.i.=Long tons per square inch.
U.T.S.=Ultimate tensile stress.
P.S.=Proof stress.
¹ The impact transition temperature is taken as that at which the fracture is 50% fibrous.

In manufacturing articles from the alloy steels described above, the heat treatment employed may be of the kind described in U.S. Patent No. 2,992,148 comprising a double austenitizing and hardening treatment followed by tempering and cooling. Alternatively, a heat treatment consisting of a single austenitizing and hardening followed by single or double tempering may be used.

Advantageously, the austenitizing temperature in a single-stage austenitizing treatment is 810° C. to 840° C., while in a two-stage treatment, the first stage comprises heating at 870° C. to 920° C. and the steel is then slowly cooled and heated at 810° C. to 840° C. in the second stage. The final tempering temperature is advantageously from 590° C. to 610° C. In this temperature range, large forgings can be adequately stress-relieved in a reasonable heating time, e.g., 48-96 hours, with little practical risk of the Ae₁ temperature being exceeded. Upon heat treatment the alloy steels have a microstructure which is essentially bainite.

For the purpose of giving those skilled in the art a better understanding of the invention and/or a better appreciation of the advantages of the invention, the following illustrative example is given:

Example I

Alloy steels having compositions within the invention and another steel outside the invention (Alloy No. 1) were prepared and are identified in Table I:

TABLE I

Steel No.	Chemical Composition (Percent by Weight)								
	C	Si	Mn	S	P	Ni	Cr	Mo	Co
1-----	0.26	0.15	0.42	0.006	0.012	4.0	1.50	0.29	-----
2-----	0.26	0.24	0.55	0.013	0.011	4.15	1.50	0.35	2.14
3-----	0.26	0.25	0.54	0.016	0.012	4.15	1.55	0.34	3.08
4-----	0.25	0.20	0.45	0.005	0.002	4.30	1.58	0.37	4.67

All the steels were melted and cast in air and were heat treated in the form of 5/8 inch diameter bar forged from the cast ingots. The bars were austenitized for two hours at 840° C. and were then furnace-cooled to room temperature at an average rate of 53° C./hour over the range 700° C. to 300° C. This was calculated to simulate

TABLE III

Steel No.:	Ampere-turns/inch
1-----	1190
2-----	1170
3-----	960
4-----	690

The Ac₁ temperature of alloys No. 2, 3 and 4 were 692° C., 700° C. and 709° C., respectively. It will be appreciated, of course, that the Ac₁ temperatures are slightly above the equilibrium Ae₁ temperatures, and the Ae₁ temperatures of alloy Nos. 2, 3 and 4 are all estimated to be over 675° C. For example, the Ae₁ temperature of alloy No. 3 is estimated to be 690° C. This illustrates that alloy steels within the invention can be stress-relieved or tempered at temperatures well over 600° C. while achieving a markedly satisfactory combination of metallurgical properties as particularly illustrated by alloy Nos. 3 and 4 which contained cobalt in amounts between about 3% and 5%. Alloy No. 4 manifested the best combination of mechanical and magnetic properties, particularly from the viewpoint of the latter where only 690 ampere-turns per inch were required to induce a flux density of 130 kilolines per square inch. The improvement in the magnetic properties resulting from the presence of cobalt is also shown in the accompanying drawing in which the magnetic induction is plotted against the field strength for each of the four steels.

Alloy steels within the instant invention are quite useful for diverse applications. Not only can large forgings be produced but also plates, castings carburized parts, etc. While it is indicated that the heat treatments described hereinbefore involve slow cooling operations, it is to be understood that alloy steels within the invention can be liquid-quenched with satisfactory results, particularly where liquid-quenching treatments would be practicable.

Although the present invention has been described in conjunction with preferred embodiments, it is to be understood that modifications and variations may be resorted to without departing from the spirit and scope of the invention, as those skilled in the art will readily understand. Such modifications and variations are considered to be within the purview and scope of the invention and appended claims.

We claim:

1. An alloy steel characterized by good magnetic induction properties together with a low impact transition temperature and being particularly adaptable for use as forgings in the manufacture of rotors consisting essentially of about 0.2% to about 0.3% carbon, about 0.2% to about 0.6% manganese, about 4% to about 4.5% nickel, about 2% to about 5% cobalt, about 0.25% to about 0.5% molybdenum, up to about 0.2% vanadium, up to 0.4% silicon, about 1% to about 1.5% chromium with the balance being essentially iron, said alloy steel being further characterized in having an A_{e1} temperature of at least 600° C.

2. An alloy steel as set forth in claim 1 wherein cobalt is present in an amount of at least 3%.

3. As a new article of manufacture, a rotor formed from the alloy steel set forth in claim 1.

4. As a new article of manufacture, a generator rotor formed from the alloy steel set forth in claim 2.

5. An alloy steel characterized by good magnetic induction properties together with a low impact transition temperature and consisting essentially of about 0.1% to about 0.5% carbon, about 0.2% to about 1% manganese, about 3.5% to about 5.5% nickel, about 1.5% to about 10% cobalt, about 0.2% to about 0.5% molybdenum, up to 0.5% vanadium, up to 0.5% silicon, about 1% to about 2% chromium, with the balance being essentially iron, said alloy steel being further characterized in having an A_{e1} temperature of at least 600° C.

6. As a new article of manufacture, a rotor formed from the alloy steel set forth in claim 5.

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