



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
24.02.2010 Bulletin 2010/08

(51) Int Cl.:
C21D 6/02 (2006.01) **C21D 6/00** (2006.01)
C22C 38/08 (2006.01)

(21) Application number: **09251975.0**

(22) Date of filing: **11.08.2009**

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO SE SI SK SM TR
Designated Extension States:
AL BA RS

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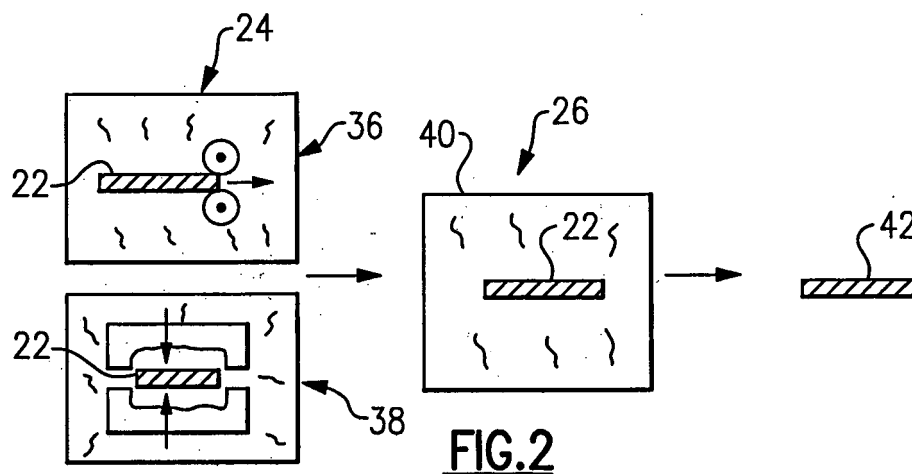
(30) Priority: **14.08.2008 US 191375**

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(54) **Method of processing maraging steel**

(57) A method of processing a workpiece of maraging steel includes receiving a workpiece (22) of maraging steel that has been subjected to thermomechanical processing (38, 36) at an austenite solutionizing temper-

ature and then directly aging (26) the workpiece of maraging steel at an aging temperature to form precipitates within a microstructure of the workpiece (42) of maraging steel, without any intervening heat treatments between the thermomechanical processing and the direct aging.



Description

[0001] This disclosure relates to maraging steel and, more particularly, to an economic method of processing maraging steel to achieve improved mechanical properties.

[0002] Maraging steel grades are generally regarded as high strength steels that do not include carbon. The high strength is obtained through thermal processing to form a predominantly martensitic microstructure. For instance, maraging steels are typically solution annealed at a temperature sufficient to form an austenite phase and then cooled to room temperature to transform the austenite phase into the martensitic phase. Several solution annealing steps are typically used to provide a homogenous microstructure. The maraging steel may subsequently be aged at a lower temperature to precipitation harden the maraging steel.

[0003] Although the above thermal processing is effective for obtaining the martensitic microstructure, a particular end use of the maraging steel may require other processing steps which alter the final microstructure and mechanical properties of the maraging steel. Thus, between the thermal processing and other processing steps, there may be countless combinations and variables that influence the microstructure and physical properties.

[0004] The disclosed methods of processing a workpiece of maraging steel are intended to provide economic processing and improved mechanical properties.

[0005] In one example, a method of processing includes receiving a workpiece of maraging steel that has been subjected to thermomechanical processing at an austenite solutionizing temperature and directly aging the workpiece of maraging steel at an aging temperature to form precipitates within a microstructure of the workpiece of maraging steel, without any intervening heat treatments between a thermomechanical processing and the direct aging.

[0006] In another aspect, the method may include thermomechanically processing the workpiece of maraging steel at the austenite solutionizing temperature prior to directly aging the workpiece of maraging steel.

[0007] In another aspect, a method includes processing a workpiece of maraging steel that has been subjected to thermomechanical processing at an austenite solutionizing temperature to thereby produce a component of maraging steel. The workpiece of maraging steel is directly aged at an aging temperature to form precipitates within the microstructure of the workpiece of maraging steel and establish an ultimate tensile strength of the component of maraging steel that is greater than 265 ksi (1.83 GPa), without any intervening heat treatments between the thermomechanical processing and the direct aging.

[0008] A preferred embodiment of the present invention will now be described in greater detail by way of example only and with reference to the accompanying drawings, in which :

Figure 1 illustrates an example method of processing a workpiece of maraging steel;

Figure 2 schematically illustrates an example implementation of the method; and

Figure 3 illustrates a polished and etched cross-section of a portion of a component of maraging steel.

[0009] Figure 1 illustrates an example method 20 of processing a workpiece of maraging steel 22 (see Figure 2). The disclosed workpiece of maraging steel 22 may have any form, such as a sheet, ingot, or casting. As will be described, the method 20 may be used to economically process the workpiece of maraging steel 22 to provide improved properties.

[0010] The workpiece of maraging steel 22 is formed of a maraging steel alloy composition. For example, the maraging steel alloy composition includes 17wt%-19wt% of nickel, 8wt%-12wt% of cobalt, 3wt%-5wt% of molybdenum, 0.2wt%-1.7wt% of titanium, 0.05wt%-0.15wt% of aluminum, and a balance of iron. As can be appreciated, the composition may vary from the given example composition. In some examples, the given composition consists essentially of the given elements and impurities that do not affect the properties of the alloy or elements that are unmeasured or undetectable in the alloy. For example, the alloy generally does not include carbon, but may include up to about 0.03wt% of carbon as an impurity. The maraging steel alloy may also be classified by composition, such as by commonly used designations M200, M250, M300, or M350.

[0011] The example method 20 includes a thermomechanical processing step 24 that includes working (e.g., plastically deforming) the workpiece of maraging steel 22 at an austenite solutionizing temperature. The process of working may include any suitable type of process, such as rolling, forging, or any forming process. The austenite solutionizing temperature may depend somewhat on the selected composition of the maraging steel. However, in most instances, the austenite solutionizing temperature will be 1500°F - 1750°F (816°C - 954°C) to solutionize the compositional components of the maraging steel into a gamma austenite phase microstructure. The workpiece of maraging steel 22 may be subjected to the austenite solutionizing temperature for the duration of the working process.

[0012] The thermomechanical processing step 24 also includes cooling the workpiece of maraging steel 22 from the austenite solutionizing temperature to transform the gamma austenite phase to an alpha martensite phase. For example, the workpiece of maraging steel 22 may be cooled to a temperature below the austenite solutionizing temperature, such as ambient (approximately 72°F or 22°C). However, other cooling temperatures may be selected.

[0013] After the thermomechanical processing step 24, the workpiece of maraging steel 22 is subjected to a direct

aging step 26. For instance, the direct aging step 26 includes heat treating the workpiece of maraging steel 22 at an aging temperature to form precipitates within the martensitic microstructure. The term "direct aging" refers to aging the workpiece of maraging steel 22 without conducting any intervening heat treatments between the thermomechanical processing step 24 and the direct aging step 26. In some examples, any processing that occurs between the thermomechanical processing step 24 and the direct aging step 26 is conducted at temperatures no greater than room temperature (approximately 72°F or 22°C). In others examples, any processing that occurs between the thermomechanical processing step 24 and the direct aging step 26 is conducted at temperatures no greater than the aging temperature of the direct aging step 26. Therefore, relative to any heat treatments, the workpiece of maraging steel 22 proceeds directly from the thermomechanical processing step 24 to the direct aging step 26.

[0014] The direct aging step 26 may be conducted at any suitable aging temperature and for any suitable amount of time, depending upon the desired end mechanical properties of the workpiece of maraging steel 22 and the material composition. For instance, the aging temperature may be 850°F - 950°F (454°C - 510°C). In one example, the direct aging step 26 includes heating the workpiece of maraging steel 22 at a temperature of about 900°F (482°C) for about nine hours to precipitation strengthen the martensitic microstructure. As can be appreciated by those skilled in the art, the aging time may vary depending on the desired degree of precipitation.

[0015] The thermomechanical processing step 24 and the direct aging step 26 of the method 20 need not be conducted serially. That is, the thermomechanical processing step 24 may be conducted at one facility or site, and the direct aging step 26 may be conducted at another facility or site. Thus, from the perspective of a single processor, the thermomechanical processing step 24 of the method 20 may be regarded as receiving the workpieces of maraging steel 22 that have already been thermomechanically processed, and subsequently conducting the direct aging step 26.

[0016] As illustrated in Table I below, processing the workpiece of maraging steel 22 according to the examples disclosed herein provides desirable mechanical properties compared with control specimens that are solution heat treated between thermomechanical processing and aging. That is, the control specimens include an additional step of heat treating compared to the example method 20. As can be appreciated from Table I, the workpiece of maraging steel 22 (Directly Aged Specimen) processed according to method 20 provides a higher 0.2% yield strength and ultimate tensile strength than the control specimen. The % elongation of the workpiece of maraging steel 22 is somewhat lower than the control specimen; however, for some end uses the loss of elongation may not be a significant factor. The hardness of the directly aged workpiece of maraging steel 22 and the control specimen are each between about 56-58 Rc.

Table I

Test Temp.	0.2% Yield Strength, ksi (MPa)		Ultimate Tensile Strength, ksi (MPa)		Elongation, %	
	Directly Aged Specimen	Control Specimen	Directly Aged Specimen	Control Specimen	Directly Aged Specimen	Control Specimen
70°F	279 (1924)	256 (1765)	290 (1999)	265 (1827)	9.5	11.5
800°F	226 (1558)	211 (1455)	242 (1669)	221 (1524)	11	12

[0017] Figure 2 schematically illustrates an example implementation of the method 20. For instance, the thermomechanical processing step 34 may include any type of thermomechanical processing, such as rolling 36, forging 38, or other forming process. The rolling 36 or forging 38 may be conducted at the austenite solutionizing temperature. In some examples, the workpiece of maraging steel 22 is a cast form that is then forged into an ingot using the forging 38 process or rolled into a sheet using the rolling 36 process.

[0018] After the thermomechanical processing step 24, the workpiece of maraging steel 22 is subjected to the direct aging step 26 in a chamber 40 at an appropriate aging temperature for a predetermined amount of time. As can be appreciated, multiple workpieces of maraging steel 22 may be aged in the chamber 40 at the same time.

[0019] After the direct aging step 26, the workpiece of maraging steel 22 is removed from the chamber 40 and allowed to cool in air for example to a temperature less than 850°F (454°C), such as room temperature. Once cooled, the workpiece of maraging steel 22 may be considered to be a component of maraging steel 42. The component of maraging steel 42 may be subjected additional processes to produce an end component, such as finishing, coating, etc.

[0020] Figure 3 schematically illustrates a cross-section of a portion of the component of maraging steel 42 that has been polished and etched to reveal a microstructure. The component of maraging steel 42 has undergone the thermomechanical processing step 24 and the direct aging step 26 as described above. The microstructure includes martensitic grains 50 having an average ASTM grain size of 10. For example, the ASTM grain size may be determined according to ASTM E112. Additionally, the microstructure includes precipitates 52 (e.g., Ni₃Mo and Ni₃Ti) near the grain boundaries of the martensitic grains 50. As discussed above, the precipitates 52 are formed during the direct aging step 26 as

elements from the composition that precipitate out of solution as intermetallic particles. The precipitates 52 generally function to strengthen the component of maraging steel 42.

[0021] In general, the size of the grains 50 and the presence of the precipitates 52 contribute to the improved mechanical properties as illustrated in Table I. For comparison, martensitic grains of the control specimen of Table I are generally larger in size and may contribute to the lower ultimate tensile strength and 0.2% yield strength. Thus, the disclosed method 20 provides a desirable combination of forming and heat treating the workpiece of maraging steel 22 to obtain improved properties, and an economic process that eliminates the need for a heat treatment step between the thermo-mechanical processing step 24 and the direct aging step 26.

[0022] The present invention also extends to a component produced according to a preferred method of the present invention.

[0023] Although a combination of features is shown in the illustrated examples, not all of them need to be combined to realize the benefits of various embodiments of this disclosure. In other words, a system designed according to an embodiment of this disclosure will not necessarily include all of the features shown in any one of the Figures or all of the portions schematically shown in the Figures. Moreover, selected features of one example embodiment may be combined with selected features of other example embodiments.

Claims

1. A method of processing a workpiece (22) of maraging steel, comprising:
 - receiving a workpiece of maraging steel that has been subjected to thermomechanical processing at an austenite solutionizing temperature; and
 - directly aging (26) the workpiece of maraging steel at an aging temperature to form precipitates within a micro-structure of the workpiece of maraging steel, without any intervening heat treatments between the thermomechanical processing and the direct aging.
2. A method as claimed in claim 1, further including selecting the aging temperature to be about 850° F - 950° F (454-510°C).
3. A method as claimed in claim 2, wherein the selected aging temperature is about 900° F.
4. A method as claimed in any of claims 1 to 3, further including cooling the workpiece (22) of maraging steel in air from the aging temperature to a temperature less than 850° F.
5. A method as claimed in any preceding claim, further including selecting the workpiece (22) of maraging steel to include a composition comprising 17wt%-19wt% of nickel, 8wt%-12wt% of cobalt, 3wt%-5wt% of molybdenum, 0.2wt%-1.7wt% of titanium, 0.05wt%-0.15wt% of aluminum, and a balance of iron.
6. A method as claimed in any preceding claim, further including selecting the aging temperature to be about 900° F (482°C), and subjecting the workpiece (22) of maraging steel to the aging temperature for about nine hours.
7. A method of processing a workpiece (22) of maraging steel, comprising:
 - thermomechanically processing a workpiece of maraging steel at an austenite solutionizing temperature; and
 - directly aging (26) the workpiece of maraging steel at an aging temperature to form precipitates within a micro-structure of the workpiece of maraging steel, without any intervening heat treatments between the thermomechanical processing and the direct aging.
8. A method as claimed in claim 7, wherein the thermomechanical processing includes forging (38).
9. A method as claimed in claim 7, wherein the thermomechanical processing includes rolling (36).
10. A method as claimed in any of claims 7 to 9, further including selecting the workpiece of maraging steel to include a composition comprising 17wt%-19wt% of nickel, 8wt%-12wt% of cobalt, 3wt%-5wt% of molybdenum, 0.2wt%-1.7wt% of titanium, 0.05wt%-0.15wt% of aluminum, and a balance of iron.
11. A method as claimed in any of claims 7 to 10, wherein the thermomechanical processing (38, 36) and the direct

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aging (26) provide the workpiece (42) of maraging steel with an average ASTM grain size of 10.

12. A method of processing a workpiece (22) of maraging steel, comprising:

5 processing a workpiece of maraging steel that has been subjected to thermomechanical processing (38, 36) at an austenite solutionizing temperature, to thereby produce a component of maraging steel (42); and
 establishing at a temperature of 850° F - 950° F (454-510°C) an ultimate tensile strength of the component of maraging steel that is greater than 265 ksi (1.83 GPa) by directly aging the workpiece of maraging steel at an
10 aging temperature to form precipitates within a microstructure of the workpiece of maraging steel, without any intervening heat treatments between the thermomechanical processing and the direct aging.

13. A method as claimed in claim 12, further including establishing an ultimate tensile strength of at least about 290 ksi (2.0 GPa).

15 **14.** A method as claimed in claim 12 or 13, further including establishing a % elongation of about 9.5%.

15. A method as claimed in any of claims 12 to 14, further including establishing a 0.2% yield strength that is greater than 256 ksi (1.77 GPa), more preferably establishing a 0.2% yield strength of at least about 279 ksi (1.92 GPa).

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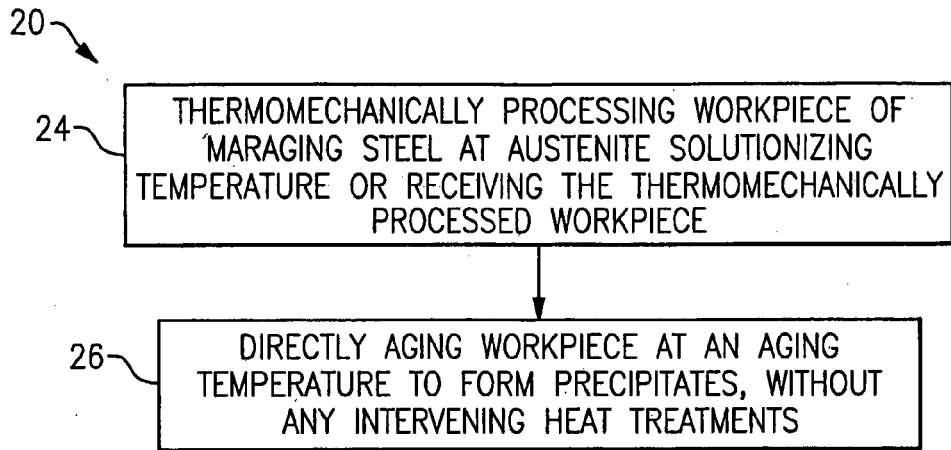


FIG.1

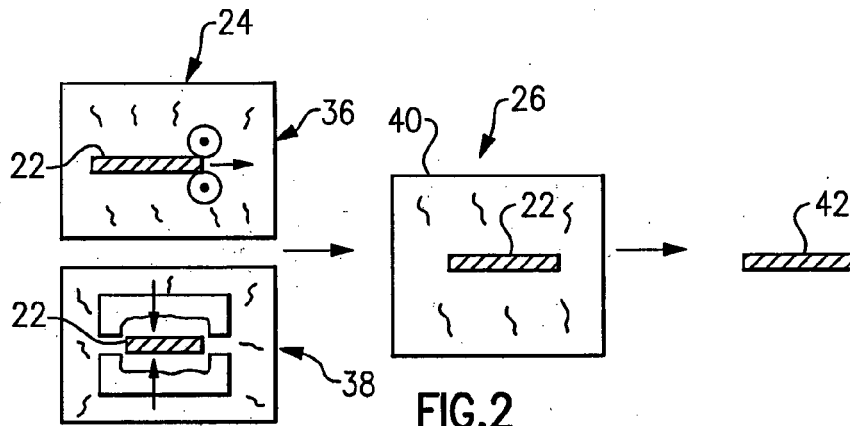
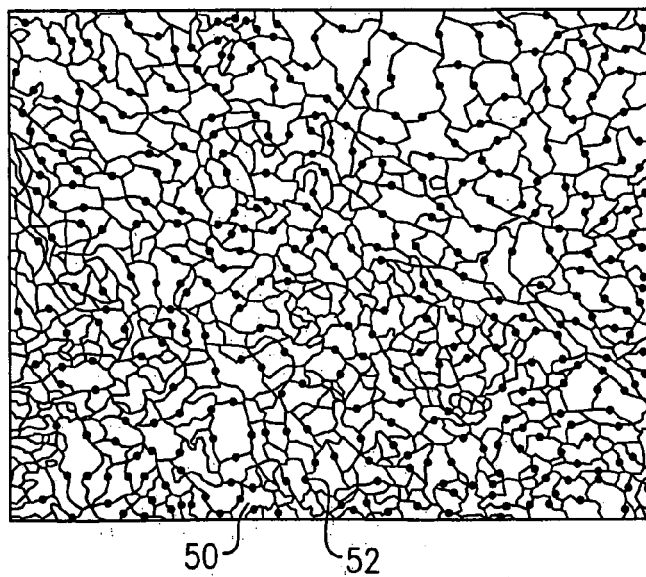


FIG.2

FIG.3





EUROPEAN SEARCH REPORT

Application Number
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Place of search Munich		Date of completion of the search 17 November 2009	Examiner Catana, Cosmin
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons ----- & : member of the same patent family, corresponding document	

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EUROPEAN SEARCH REPORT

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Place of search Munich		Date of completion of the search 17 November 2009	Examiner Catana, Cosmin
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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**ANNEX TO THE EUROPEAN SEARCH REPORT
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The members are as contained in the European Patent Office EDP file on
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