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(54) **METHODS FOR IMPROVING MECHANICAL PROPERTIES OF A BETA PROCESSED TITANIUM ALLOY ARTICLE**

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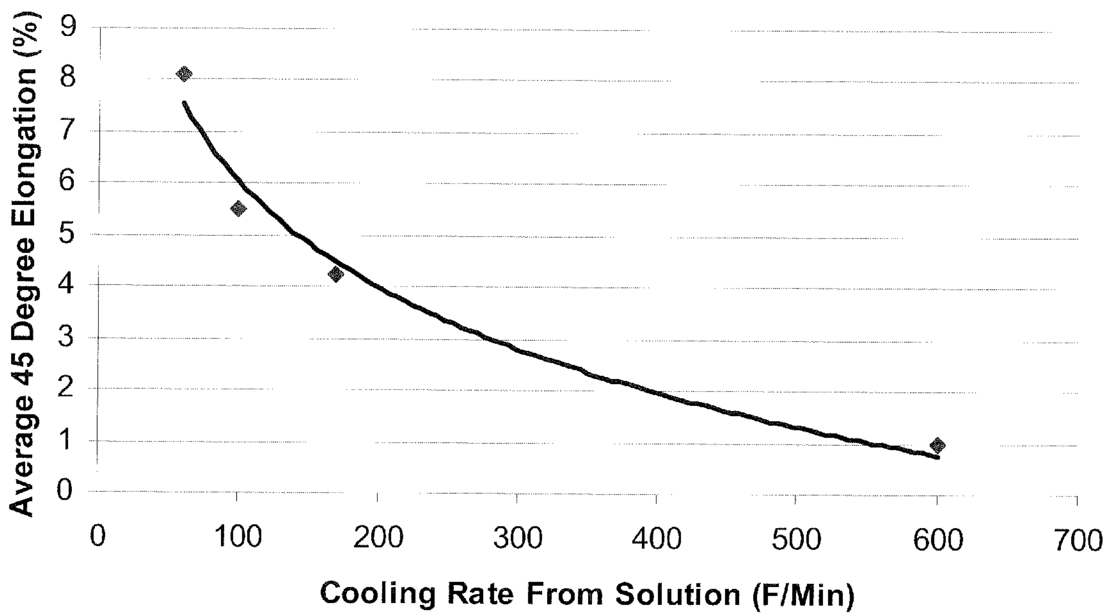
(57) **ABSTRACT**

Methods for improving mechanical properties of beta processed, alpha-beta titanium alloy articles involving forging the alloy article above the beta transus to produce a post final forged article, subjecting the post final forged article to a post-forged cooling process to produce a post-forged cooled article, solution heat treating the post-forged cooled article to a temperature below the beta transus to produce a solution heat treated article, subjecting the solution heat-treated article to a controlled post-solution cooling process to produce a post-solution cooled article, and alpha phase precipitation treating the post-solution cooled article to obtain a final article having an average elongation value of at least about 3%.



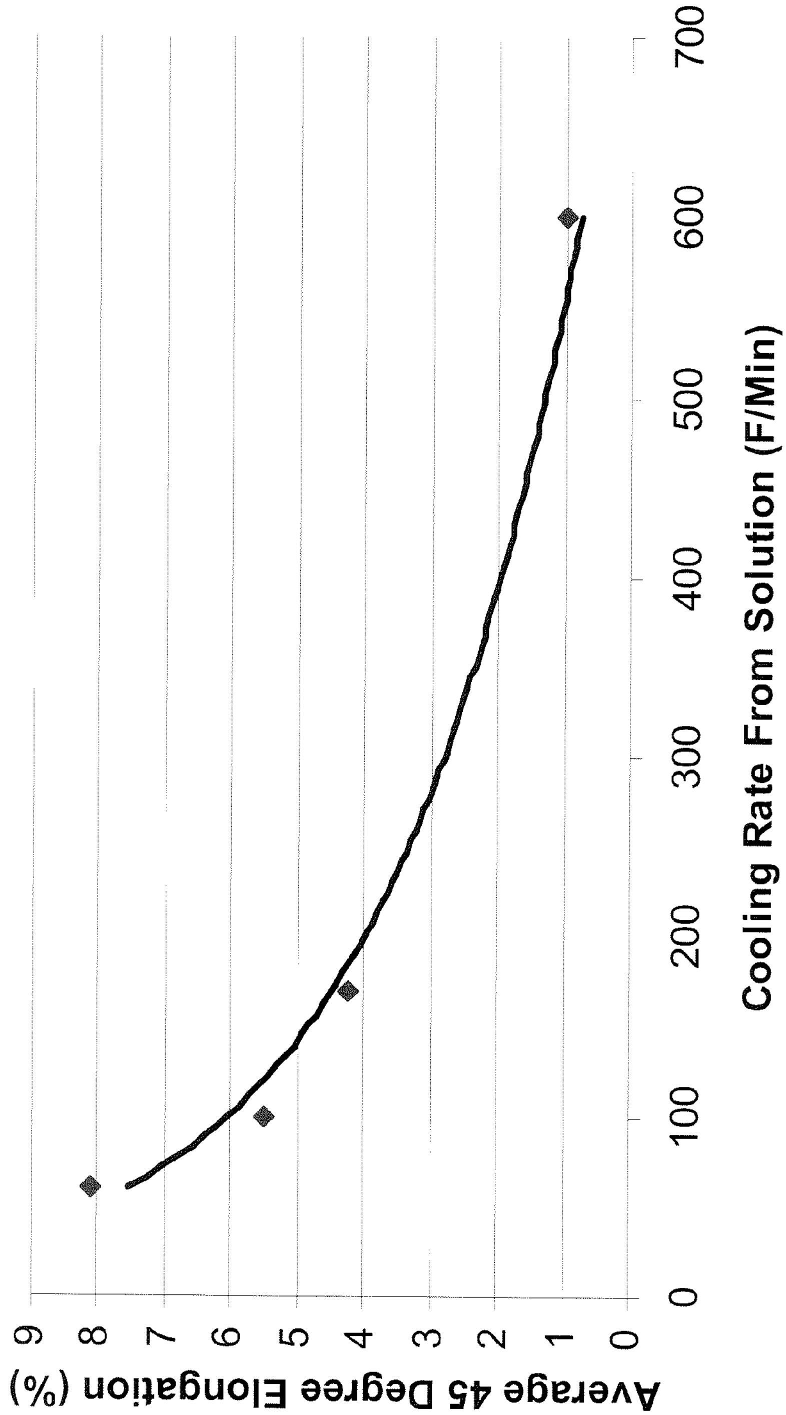

Average 45 Degree Elongation (%)
0
1
2
3
4
5
6
7
8
9
Cooling Rate From Solution (F/Min)
0
100
200
300
400
500
600
700

FIG. 1

METHODS FOR IMPROVING MECHANICAL PROPERTIES OF A BETA PROCESSED TITANIUM ALLOY ARTICLE

TECHNICAL FIELD

[0001] Embodiments described herein generally relate to methods for improving mechanical properties of a beta processed titanium alloy article. More particularly, embodiments herein generally describe methods for improving the ductility of a beta processed Ti-6246 article.

BACKGROUND OF THE INVENTION

[0002] Turbine engine designers are continuously looking for new materials with improved properties for reducing engine weight and obtaining higher engine operating temperatures. In order to function in this environment, materials used must have sufficient creep strength to survive and perform properly, and must also maintain sufficient ductility, toughness, and strength at both room and elevated temperatures to be producible and fracture resistant in service. Titanium alloys (Ti alloys) possess a promising combination of low-temperature mechanical properties, and high intermediate temperature strength and creep resistance. For these reasons, Ti alloys have the potential to replace nickel-based superalloys, which are currently used to make numerous turbine engine components.

[0003] Beta processed alpha-beta titanium alloys are one type of titanium alloy that can be used to manufacture components suitable for use in gas turbine engines. Alpha-beta titanium alloys are alloys having more titanium than any other element, and which form predominantly two phases upon heat treatment, an alpha phase and a beta phase. In alpha-beta (α-β) titanium alloys, the alpha (α) phase is a hexagonal close packed (HCP) phase that is thermodynamically stable at lower temperatures, and the beta (β) phase is a body centered cubic (BCC) phase that is thermodynamically stable at temperatures above the "beta transus," which is a temperature that is particular to the alloy. Below the beta transus, a mixture of alpha and beta phases is thermodynamically stable.

[0004] In general, these alloys have excellent mechanical properties relative to their weight, at both room temperature and moderate elevated temperatures as high as about 1200° F. (about 649° C.). Such alloys can be used to make parts such as fan and compressor disks, blisks, blades, vanes, shafts, and engine mounts, for example.

[0005] Processing alpha-beta titanium alloys above the beta transus temperature can result in a greater than approximately 50° F. (about 28° C.) increase in creep strength when compared to the same material processed below the beta transus temperature. However, when alpha-beta titanium alloys are beta processed to increase high temperature capability, the material can suffer from low ductility, on average less than about 3% for example, when tested at angles of from about 35 to about 55 degrees from the grain flow. Minimum ductility is frequently encountered when the test axis angle approaches 45 degrees from the grain flow. See Krull, T. et al., *Mechanical Properties of* β*-processed Ti* 6246; Ti-2003 Science and Technology; Proceedings of the 10th World Conference on Titanium, Hamburg, Germany; 13-18 Jul. 2003. pp. 1871-1878.

[0006] Therefore, there remains a need for methods for making beta processed alpha-beta titanium alloys having increased temperature capability and acceptable strength, while maintaining adequate ductility.

BRIEF DESCRIPTION OF THE INVENTION

[0007] Embodiments herein generally relate to methods for improving mechanical properties of beta processed, alpha-beta titanium alloy articles comprising forging the alloy article above the beta transus to produce a post final forged article, subjecting the post final forged article to a post-forged cooling process to produce a post-forged cooled article, solution heat treating the post-forged cooled article to a temperature below the beta transus to produce a solution heat treated article, subjecting the solution heat-treated article to a controlled post-solution cooling process to produce a post-solution cooled article, and alpha phase precipitation treating the post-solution cooled article to obtain a final article having an average elongation value of at least about 3%.

[0008] Embodiments herein also generally relate to methods for improving mechanical properties of a Ti-6Al-2Sn-4Zr-6Mo alloy article having a beta transus of about 1735° F. (about 946° C.) comprising forging the alloy article above the beta transus to produce a post final forged article, subjecting the post final forged article to a post-forged cooling process to produce a post-forged cooled article, solution heat treating the post-forged cooled article to a temperature below the beta transus to produce a solution heat treated article, subjecting the solution heat-treated article to a controlled post-solution cooling process to produce a post-solution cooled article, and alpha phase precipitation treating the post-solution cooled article to obtain a final article having an average elongation value of from about 5% to about 5.8%.

[0009] Embodiments herein also generally relate to methods for improving mechanical properties of a Ti-6Al-2Sn-4Zr-6Mo alloy article having a beta transus of about 1735° F. (about 946° C.) comprising forging the alloy article to a temperature of from about 1745° F. to about 1825° F. (about 952° C. to about 996° C.) to produce a post final forged article, subjecting the post final forged article to a post-forged cooling process comprising cooling the post-forged article at a post-forged cooling rate of from about 150° F./minute to about 400° F./minute (about 83° C./minute to about 222° C./minute) while the temperature of the post final forged article is between about the beta transus and about 700° F. (about 371° C.) to produce a post-forged cooled article, solution heat treating the post-forged cooled article to a temperature below the beta transus of from about 165° F. to about 225° F. (about 92° C. to about 125° C.) for about 4 hours to produce a solution heat treated article, subjecting the solution heat-treated article to a controlled post-solution cooling process comprising cooling the solution heat-treated article at a controlled post-solution cooling rate of from about 50° F./minute to about 200° F./minute (about 28° C./minute to about 111° C./minute) to produce a post-solution cooled article, and alpha phase precipitation treating the post-solution cooled article at a temperature of from about 1100° F. to about 1350° F. (593° C. to about 732° C.) for about 8 hours to obtain a final article having an average elongation value of from about 5% to about 5.8%.

[0010] These and other features, aspects and advantages will become evident to those skilled in the art from the following disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] While the specification concludes with claims particularly pointing out and distinctly claiming the invention, it is believed that the embodiments set forth herein will be better understood from the following description in conjunction with the accompanying figures, in which like reference numerals identify like elements.

[0012] FIG. **1** is a ductility plot reflecting the results described in the EXAMPLE.

DETAILED DESCRIPTION OF THE INVENTION

[0013] Embodiments described herein generally relate to methods for improving mechanical properties of a beta processed titanium alloy article. In particular, embodiment described herein generally relate to methods for improving the ductility of Ti-6246 (Ti-6Al-2Sn-4Zr-6Mo) articles. While the description herein focuses on Ti-6246, those skilled in the art will understand that the methods herein should not be limited to such, and may be equally applicable to any alpha-beta titanium alloy such as, but not limited to, Ti-6242 (Ti-6Al-2Sn-4Zr-2Mo), Ti-6-22-22S (Ti-6Al-2Sn-2Zr-2Mo-2Cr-0.25Si), and Ti-17 (Ti-5Al-4Mo-4Cr-2Sn-2Zr).

[0014] As set forth herein below, Ti-6246 (referred to henceforth as the "alloy") can be processed to improve mechanical properties, and in particular, ductility, without negatively impacting other properties below acceptable limits. Initially, the alloy can be forged in the beta phase field to produce a post final forged article. Ti-6246 has a beta transus temperature of about 1735° F. (about 946° C.) and forging can be carried out from about 10° F. to about 90° F. (about 6° C. to about 50° C.) above the beta transus temperature, or from about 1745° F. to about 1825° F. (about 952° C. to about 996° C.). This forging temperature can help assure that the alloy is substantially all in the beta phase while minimizing excessive beta grain growth. Because it is desirable that the finished machined article within the forging envelope remains above the beta transus temperature substantially throughout the forging process, heated dies can be used. Those skilled in the art of forging will understand that a variety of specific die temperatures and strain rates can be employed to achieve this effect. Independent of the particular forging operation performed, the embodiments described herein below can be applied post-forging. In general, however, beta forging of alpha-beta titanium alloys can employ a height reduction in the post final forged article of at least about 30%.

[0015] Upon completion of the final forging step, the post final forged article can be subjected to a post-forged cooling process using a variety of cooling techniques known to those skilled in the art, such as, but not limited to, fan air, oil, gas, and water quenching, to produce a post-forged cooled article. The cooling rate of this post-forged cooling process can be controlled to maintain a balance between strength and ductility in the final article. In one embodiment, from the beta transus to about 700° F. (about 371° C.), the post-forged cooling rate may generally be from about 150° F./minute to about 400° F./minute (about 83° C./minute to about 222° C./minute). This post-forged cooling rate can be maintained until the article reaches a temperature of about 700° F. (about 371° C.). Below approximately 700° F. (about 371° C.), the cooling rate is less significant and the article can be cooled at any rate.

[0016] It should be noted that the cooling rate used for the post-forged cooling process can be dependent on several factors. In some instances, the post-forged cooling rate can be outside of the previously described range of from about 150° F./minute to about 400° F./minute (about 83° C./minute to about 222° C./minute) due to such factors as forging process, article section size, and post-forged cooling configurations, for example. For the purposes of the embodiments herein, the cooling rate of the post-forged cooling process has a secondary effect on ductility, with the primary effect being attributable to the subsequent heat treatment described below.

[0017] The post-forged cooled article can then be solution heat treated to a temperature of from about 165° F. to about 225° F. (about 92° C. to about 125° C.) below the beta transus, and held for about 4 hours to produce a solution heat-treated article. This solution heat-treated article can then be subjected to a controlled post-solution cooling process to produce a post-solution cooled article. Methods suitable for use in the solution heating process will be known to those skilled in the art. Examples of solution heat-treating methods can include heat-treating in air, vacuum, or inert (i.e. argon) atmospheres. The controlled post-solution cooling process can have the most significant impact on achieving the desired ductility and may again involve a variety of cooling techniques known to those skilled in the art, such as fan air, oil, gas, and water quenching. The controlled post solution-cooling rate may be from about 50° F./minute to about 200° F./minute (about 28° C./minute to about 111° C./minute).

[0018] The configuration of the post forged cooled article, which may involve rough machining after the final forge operation, and the specific cooling method, may be selected to achieve the desired controlled post-solution cooling rate range. In portions of the article where ductility is of less concern, controlled post-solution cooling rates above the desired range are acceptable. Similarly, controlled post-solution cooling rates that fall below the desired range are acceptable in portions of the article where lower strength is allowable.

[0019] After the controlled post-solution cooling, the post-solution cooled article may be subjected to an alpha phase precipitation treatment at a temperature of from about 1100° F. (about 593° C.) to about 1350° F. (about 732° C.) for a period of about 8 hours, followed by uncontrolled cooling to about room temperature, to produce a final article. This precipitation treatment can provide the final article with its desired strength and can be carried out in multiple steps to facilitate manufacturing. For example, the alpha phase precipitation may be split into two or more exposures to relieve residual stresses generated during machining or joining operations.

[0020] In final articles resulting from the previously described process, strength is reduced, creep is maintained and 45 degree angle ductility is improved to at least about 3% when compared with conventionally beta processed and heat treated alpha beta titanium alloys. As used herein throughout, ductility elongation values are measured using a room temperature tensile test elongation taken at 45 degrees to the grain flow. More specifically, the resulting final article can have an average elongation value of at least about 5%, and in one embodiment from about 5% to about 5.8%.

EXAMPLE

[0021] A systematic study of variable thermal response relationships was performed on Ti-6Al-2Sn-4Zr-6Mo (nominal) alloy, which has a beta transus (βt) temperature of about 1745° F. (952° C.). The study was carried out as follows:

[0022] A forging billet was cut to a diameter of about 8 inches (about 20.3 cm) and a length of about 10.5 inches (about 26.7 cm) and heated to a nominal temperature of beta transus (βt) plus 50° F. (28° C.).

[0023] The heated billet was then beta forged into a pancake shape having a diameter of about 13 inches (about 33.0 cm) and a thickness of about 4 inches (10.2 cm), which equated to a forging height reduction of about 2.5:1, or about 60%.

[0024] The final forged article was then subjected to a post-forged cooling process. Air cooling was used to cool the article at a rate of about 40° F. (about 22° C.) per minute until the article reached room temperature.

[0025] The post-forged cooled article was then cut into four pieces, each piece comprising about ⅛, or less, of the article. The four pieces were then solution heat treated for approximately 4 hours with each piece being treated at a different temperature as outlined below:

[0026] Piece **1**: 1695° F. (924° C.), or βt—50° F. (28° C.)

[0027] Piece **2**: 1645° F. (896° C.), or βt—100° F. (56° C.)

[0028] Piece **3**: 1595° F. (868° C.), or βt—150° F. (83° C.)

[0029] Piece **4**: 1545° F. (841° C.), or βt—200° F. (111° C.)

[0030] The solution heat treated pieces were then subjected to a controlled post solution cooling process in which the solution heat treated pieces were cooled at one of the following nominal rates:

[0031] about 40° F./min (about 22° C./min)

[0032] about 100° F./min (about 56° C./min)

[0033] about 170° F./min (about 94° C./min), or

[0034] about 600° F./min (about 333° C./min)

[0035] Once cooled to about room temperature, each piece was subjected to an alpha phase precipitation process for about 8 hours, wherein the pieces were heat treated at one of the following temperatures followed by air cooling to about room temperature:

[0036] 1100° F. (593° C.), 1150° F. (621° C.), or 1200° F. (649° C.)

[0037] The resulting final articles were then sectioned to produce tensile test specimens at nominally 45 degrees to the grain flow.

[0038] A room temperature tensile test was carried out using ASTM E8. The resulting elongation data was found to be highly dependent on cooling rate from the solution temperature as shown in FIG. **1**. For each cooling rate, the data shown in FIG. **1** represents an average of between 6 and 9 data points gathered during repeated test carried out as previously described.

[0039] This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to make and use the invention. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal language of the claims.

What is claimed is:

1. A method for improving mechanical properties of beta processed, alpha-beta titanium alloy articles comprising:

forging the alloy article above the beta transus to produce a post final forged article;

subjecting the post final forged article to a post-forged cooling process to produce a post-forged cooled article;

solution heat treating the post-forged cooled article to a temperature below the beta transus to produce a solution heat treated article;

subjecting the solution heat-treated article to a controlled post-solution cooling process to produce a post-solution cooled article; and

alpha phase precipitation treating the post-solution cooled article to obtain a final article having an average elongation value of at least about 3%.

2. The method of claim **1** comprising forging the alloy article to a temperature of from about 1745° F. to about 1825° F. (about 952° C. to about 996° C.).

3. The method of claim **2** comprising solution heat-treating the post-forged cooled article to a temperature of from about 165° F. to about 225° F. (about 92° C. to about 125° C.) below the beta transus for about 4 hours.

4. The method of claim **3** wherein the controlled post-solution cooling process comprises cooling the solution heat-treated article at a controlled post-solution cooling rate of from about 50° F./minute to about 200° F./minute (about 28° C./minute to about 111° C./minute).

5. The method of claim **4** comprising alpha phase precipitation treating the post-solution cooled article at a temperature of from about 1100° F. to about 1350° F. (593° C. to about 732° C.) for about 8 hours.

6. The method of claim **5** wherein the final article having an average elongation value of from about 5% to about 5.8%

7. The method of claim **6** wherein the titanium alloy article comprises Ti-6Al-2Sn-4Zr-6Mo.

8. A method for improving mechanical properties of a Ti-6Al-2Sn-4Zr-6Mo alloy article having a beta transus of about 1735° F. (about 946° C.) comprising:

forging the alloy article above the beta transus to produce a post final forged article;

subjecting the post final forged article to a post-forged cooling process to produce a post-forged cooled article;

solution heat treating the post-forged cooled article to a temperature below the beta transus to produce a solution heat treated article;

subjecting the solution heat-treated article to a controlled post-solution cooling process to produce a post-solution cooled article; and

alpha phase precipitation treating the post-solution cooled article to obtain a final article having an average elongation value of from about 5% to about 5.8%.

9. The method of claim **8** comprising forging the alloy article to a temperature of from about 1745° F. to about 1825° F. (about 952° C. to about 996° C.).

10. The method of claim **9** wherein the post-forged cooling process comprises cooling the post final forged article at a post-forged cooling rate of from about 150° F./minute to about 400° F./minute (about 83° C./minute to about 222° C./minute) while the temperature of the post final forged article is between about the beta transus and about 700° F. (about 371° C.).

11. The method of claim **10** comprising solution heat-treating the post-forged cooled article to a temperature of from about 165° F. to about 225° F. (about 92° C. to about 125° C.) below the beta transus for about 4 hours.

12. The method of claim **11** wherein the controlled post-solution cooling process comprises cooling the solution heat-treated article at a controlled post-solution cooling rate of from about 50° F./minute to about 200° F./minute (about 280° C./minute to about 111° C./minute).

13. The method of claim **12** comprising alpha phase precipitation treating the post-solution cooled article at a temperature of from about 1100° F. to about 1350° F. (593° C. to about 732° C.) for about 8 hours.

14. A method for improving mechanical properties of a Ti-6Al-2Sn-4Zr-6Mo alloy article having a beta transus of about 1735° F. (about 946° C.) comprising:

forging the alloy article to a temperature of from about 1745° F. to about 1825° F. (about 952° C. to about 996° C.) to produce a post final forged article;

subjecting the post final forged article to a post-forged cooling process comprising cooling the post-forged article at a post-forged cooling rate of from about 150° F./minute to about 400° F./minute (about 83° C./minute to about 222° C./minute) while the temperature of the post final forged article is between about the beta transus and about 700° F. (about 371° C.) to produce a post-forged cooled article;

solution heat treating the post-forged cooled article to a temperature of from about 165° F. to about 225° F. (about 92° C. to about 125° C.) below the beta transus for about 4 hours to produce a solution heat treated article;

subjecting the solution heat-treated article to a controlled post-solution cooling process comprising cooling the solution heat-treated article at a controlled post-solution cooling rate of from about 50° F./minute to about 200° F./minute (about 280° C./minute to about 111° C./minute) to produce a post-solution cooled article; and

alpha phase precipitation treating the post-solution cooled article at a temperature of from about 1100° F. to about 1350° F. (593° C. to about 732° C.) for about 8 hours to obtain a final article having an average elongation value of from about 5% to about 5.8%.

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