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[54] PROCESS FOR FORMING TITANIUM

[72] Inventor: **James D. Collins**, Indianapolis, Ind.

[73] Assignee: **General Motors Corporation**, Detroit, Mich.

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[58] **Field of Search** 72/364, 700; 148/11.5, 125

[56] **References Cited**

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Primary Examiner—Lowell A. Larson

Attorney—Sidney Carter and Peter P. Kozak

[57] **ABSTRACT**

A process for forming titanium and titanium alloys comprising a two-step forming process of a partial form at sub-zero temperatures followed by a final form at room temperature or above.

5 Claims, No Drawings

PROCESS FOR FORMING TITANIUM

This invention relates to metallurgical processing and particularly to a metallurigical process for forming titanium. More particularly, this invention relates to a two-step forming process to achieve increased formability of titanium and titanium alloys at temperatures substantially below those normally required to form titanium.

In recent years with the advent of high speed aircraft and high operating temperature gas turbine engines, titanium and titanium alloys have assumed a predominant position in materials for use in structural components of aircraft because of their high strength-to-weight ratio and their resistance to the high temperatures normally occurring during the operation of high speed aircraft.

Titanium alloys are classed as a hard-to-form material because of their high yield strength, which is on the order of 120 to 190 ksi. Because of their resistance to deformation, forming operations commonly take place at greater loads than would be required for lower strength alloys and at temperatures above 1,000° F. Several gas turbine engine components and structural components of aircraft require severe bending of hard-to-form alloy sheets to keep the leading edges as sharp as possible to maintain maximum gas flow efficiency. In addition, the tighter the bend that can be made in a structural element, the more efficient, i.e. lighter, it will be. For example, some engine designs require members to be bent around a radius equalling the thickness of the sheet. This type of forming operation requires a 33 percent elongation of the outer fiber of the sheet and, therefore, when forming titanium alloys, temperatures of 1,200° to 1,500° F. are recommended. For forming operations employing a radius of twice the thickness of the sheet, which is the equivalent of a 20 percent elongation of the outer fiber, forming temperatures of 1,200° F are recommended. Room temperature forming operations are recommended only when the bend radius is greater than or equal to 4.5 times the thickness of the sheet which is equivalent to a 14 to 16 percent elongation or less of the outer fiber. The degree of bend radii criticality can be reduced for a given forming operation if the forming is carried out in progressive stages with an anneal between stages. However, high temperature forming operations are undesirable because they result in excessive oxidation of the sheet and thinning of the sheet section at points of maximum deformation and because they require heating of the forming dies to excessively high temperatures which drastically decreases the life of the dies. The interstage anneal technique is also undesirable both for economic reasons and because of the progressive contamination of the material resulting from long exposure to annealing temperatures.

Accordingly, it is among the principal objects of my invention to provide a method for facilitating the formability of titanium and titanium alloys.

It is a further object of my invention to provide a process for forming titanium and titanium alloys at temperatures substantially below those normally required to achieve deformation.

It is another object of my invention to provide a two-step forming process wherein a titanium or titanium alloy workpiece is partially formed at a low temperature followed by a final form at room temperature or a moderately elevated temperature, thereby eliminating the need for interstage thermal anneals and the need for the excessively high forming temperatures normally required for forming titanium.

It is yet another object of my invention to provide a two-step forming process wherein the titanium or titanium alloy workpiece is first partially formed at a sub-zero temperature and then finished formed at a moderately elevated temperature whereby increased formability at a lesser load than is normally required for forming titanium is achieved.

In accordance with the preferred embodiment of my invention, these and other objects are accomplished by first submerging a titanium and titanium alloy workpiece in a bath of liquid nitrogen and partially forming the workpiece to about 10 percent of the total deformation required and thereafter finish forming the workpiece at a temperature of 260° F. Both the loads and temperatures required for final deformation of the titanium workpiece are substantially below those normally required in titanium forming operations and, therefore, my two-step forming process embodying my invention may be viewed as a "work softening" process.

Other objects and advantages will be apparent from the following detailed description of my invention. As used hereinafter the term titanium includes both titanium and titanium alloys containing at least about 80 percent titanium.

A few general comments may first be made concerning my work softening process. Work softening is of interest because it offers the possibility of increasing the formability of titanium by a two-step operation of plastic deformation at a low temperature followed by further deformation at room temperature or above without the requirement of an interstage anneal to remove accumulated work hardening or the excessively high working temperatures normally required for forming titanium. A theoretical requirement of the work softening mechanism is that the second deformation load at room temperature following the partial deformation at a low temperature will not reach a normal load point described by a room temperature stress-strain curve. This constitutes a failure of the mechanical equation of state. In my investigations, the two-step work softening process has shown a considerable drop of the flow stress on further straining at the higher temperature. In addition, the low temperature work hardening has been shown to be removed more completely by the second deformation than could be accomplished by a thermal anneal. This reduced load and dramatic improvement in formability satisfies the work softening requirement. Although the theoretical explanation of the work softening mechanism is not known, I believe, but without limitations thereto, that the phenomenon can be described as a catastrophic release of glide dislocations which are piled up against sessile dislocations at the low temperature to create an unstable condition at the higher temperature.

In the practice of my invention, I prefer to use liquid nitrogen as a medium in which to cool the workpiece for the low temperature forming operation because of its relatively low cost and ease of handling. However, other suitable liquified gases or cryogenic fluids known in the current cryogenic art may be used. When liquid nitrogen is used, a holding tank may be suitably modified to contain the liquid and prevent its evaporation. After cooling in the liquid nitrogen medium, the workpiece is positioned in the dies of a forming apparatus to perform a desired preforming operation such as bending, stretching, crimping, rolling, pressing and the like at the temperature of the medium.

In the method of my invention, it is necessary to perform a certain amount of deformation in order for the work softening mechanism to become operative. Investigations of work softening in single crystals has shown that a deformation of 5 to 6% is needed for the mechanism to become operative. However, in forming polycrystalline material, I find it preferable to have at least about a 10 percent deformation. The deformation may be continued above 10 percent with the amount of allowable deformation being limited only by that at which cracking or catastrophic failure of the workpiece is imminent. Although, it is not a requirement that the type of deformation, i.e., bending, stretching, etc., be the same as that at the second forming temperature since it is believed that the first forming operation is necessary only to produce a desirable dislocation arrangement, in a production operation it is desirable that the two deformations conform. That is, if the workpiece is to be bent to a desired configuration, partial bending may take place at the liquid nitrogen temperature with the final bending operation occurring thereafter at the second or moderately elevated temperature.

After the workpiece has been partially formed to 10 percent or greater deformation it is heated to room temperature, which is an environmental temperature ranging from about 65° to 90° F, or heated to a moderately elevated temperature for the finish forming operation. It has been found desirable

that the second forming operation take place as soon as possible after the partial forming operation in order to realize the maximum formability achieved by the two-step operation. It is thought that time lapses of as little as an hour between the forming operations allows the material to undergo a certain degree of recovery and it has been shown that an hours lapse substantially detracts from the formability of the material. In the preferred embodiment, the second forming operation is performed at a temperature of about 260° F for reasons which will hereinafter be fully explained. However, it will be apparent that even in the preferred embodiment, finish forming is accomplished at only a moderately elevated temperature and one which is substantially below the 1,000° to 1,500° F range normally required for forming titanium.

Reference to the following specific examples will further serve to illustrate my invention and contribute to the understanding thereof and will demonstrate the effectiveness of my invention in facilitating the formability of titanium.

EXAMPLE I

Bend test specimens having deminsions of ½ inch × 2 inches with a thickness of 0.062 inch were cut from Ti–6Al–4V and Ti–5Al–2.5Sn annealed sheet material. The former alloy was cut perpendicular to the rolling direction of the sheet, and the latter alloy was cut parallel to the rolling direction of the sheet. The Ti–6Al–4V material has a tensile strength of 135 ksi and a yield strength of 120 ksi; and the Ti–5Al–Sn material has a tensile strength of 125 ksi and a yield strength of 120 ksi. Bend test data, especially minimum bend radius, is one of the most widely reported criterion of sheet formability. Minimum bend radius is usually based on the smallest radius of 90° bend that can be made without apparent cracking under 10X magnification. The minimum room temperature bend radius for Ti–6Al–4V is 4.5 to 6t, where t = the thickness of the sheet; and for Ti–5Al–2.5Sn is 3.5 to 4.5 t.

The specimens were placed in a standard bend test machine having end loading points 1 inch apart and having a 0.125 inch center loading mandrel. The mandrel gives a 2t bend and was chosen to assure less than a 90° bend at room temperature in the material treated according to my two-step operation. A temperature of 1,000° F is normally recommended for a 2t bend in untreated material. The strain rate was 0.05 inch per minute. Table I lists the results of this test.

TABLE I. Bend Test Data For Treated and Untreated Specimens

Treatment	Material Ti-6Al-4V	Material Ti-5Al-2.5Sn
Maximum Bend Angle At Liquid Nitrogen Temperature	40° *	50° *
	70° *	35° *
	56° *	52° *
	48° *	31° *
Maximum Bend Angle At Room Temperature	74°	52°
	77°	55°
	76°	55°
Maximum Bend Angle At Room Temperature After 25° Bend in Liquid Nitrogen	115° +	77° ++
	115° +	70° ++
		70° ++
		70° ++

* Catastrophic Fracture Failure

\+ 15 minute rest between forming operations

++ 1 hour rest between forming operations

As may be seen by referring to Table I, the degree of bending achieved by my two-step operation was substantially greater than the bending achieved either at room temperature or at liquid nitrogen temperature. The Ti–6Al–4V material actually had a maximum bend angle substantially in excess of 90° at a 2t bend. The average maximum bend angle of the treated Ti–6Al–4V material was 52 percent greater than the average maximum bend angle at room temperature and for the treated Ti–5Al–2.5Sn material the average maximum bend angle was 33 percent greater than the average room temperature maximum bend angle. As previously mentioned, it has been found desirable to perform the second forming operation as soon as possible after low temperature forming. Referring to Table I, it may be seen that the Ti–5Al–2.5Sn material showed less formability than the Ti–6Al–4V. It is believed that the disparity arises from the longer rest between forming operations given the Ti–5Al–2.5Sn material than the Ti–6Al–4V material which allowed for the material to undergo a degree of recovery thereby dissipating the portion of the unstable dislocation configuration produced by the low temperature operation and thereby detracting from the formability of the material. Thus, by finish forming shortly after the partial forming operation, the recovery reaction is not allowed to take place and the maximum benefits of my two-step process may be realized.

EXAMPLE II

During the course of further bend testing of different lots of sheet material it was found that not each lot responded to the work softening operation as expected. X-ray analysis was made of the texture of the material and its change as a function of deformation history. Initial X-ray results indicated that the texture of the material which responded to the work softening operation was the same both in the direction parallel and transverse to the rolling direction. The material which did not show increased ductility was anisotropic. Further studies indicated that in the work softening material there is a high tendency for the twin plane, i.e., the (10:3) plane, to be parallel to the rolling direction; and for the anisotropic material there is a tendency for the basal plane, i.e., the (00:1) plane to be parallel to the rolling direction. This suggests that the texture may be a significant factor in the ductility differences observed.

However, it has been found that, suprisingly, this anisotropic texturing effect can be eliminated by performing the second forming operation following the liquid nitrogen forming step at 260° F rather than at room temperature. Therefore, the preferred embodiment of my invention is to carry out a partial forming operation at liquid nitrogen temperatures, and thereafter, finish form at 260° F. Tables II and III show the results of tests performed on textured Ti–6Al–4V and Ti–5Al–2.5Sn wherein the second deformation was made at 260° F. All specimens were prepared and tested according to the procedure outlined in Example I.

TABLE II. Forming Data for Ti-6Al-4V

Test Conditions	Maximum Bend Angle Parallel to Rolling Dir.	Maximum Bend Angle Transverse to Rolling Dir.
Room Temp. Bend	42°	57°
Liquid Nitrogen Bend	44°	70°
First Bend in Liquid Nitrogen Followed by Room Temp. Bend	65°	70°
First Bend in Liquid Nitrogen Followed By Bend at 260° F.	108°	109°
Bend at 260° F.	108°	82°

TABLE III. Forming Data for Ti-5Al-2.5Sn

Test Conditions	Maximum Bend Angle Parallel to Rolling Dir.	Maximum Bend Angle Transverse to Rolling Dir.
Room Temp. Bend	50°	63°

Liquid Nitrogen Bend	44°	44°
First Bend in Liquid Nitrogen Followed by Room Temp. Bend	88°	80°
First Bend in Liquid Nitrogen Followed by Bend at 260° F	106°	108°
Bend at 260° F	53°	59°

It may be seen, then, from Tables II and III that finish forming at 260° F following an initial preform at liquid nitrogen temperature results in greatly increased ductility in the material over that obtained at room temperature with the ductility being independent of the bend direction. Again, it may be seen that the material treated according to the preferred embodiment of my invention realized bend angles in excess of the 90° maximum expected. It will be recognized that 260° F acts as an activation temperature in my process and that forming operations may take place above 260° F. However, the temperature should be kept below about 600° F because of the adverse effect on the material and forming dies caused by temperatures above 600° F. Preferably the temperature is kept below about 280° F. Thus, it is apparent that the two-step forming operation embodying my invention greatly facilitates the formability of titanium and allows for drastic deformation of the titanium in forming processes at temperatures substantially below those normally required.

Although the preceding discussion has referred generally to the practice of my invention in connection with the aircraft industry, I do not intend to limit my invention thereto; and although my invention has been described in terms of specific embodiments, it is to be understood that other forms may be adopted within the scope of my invention.

I claim:

1. The process for forming titanium material comprising cooling said material to liquid nitrogen temperature, partially forming said material at said temperature to at least about 10 percent of the total deformation required in forming said material, and thereafter finish forming said material at a temperature between about room temperature and 280° F.

2. The process defined in claim 1 wherein said finish forming operation is performed at about 260° F.

3. The process for forming a sheet metal part made of titanium comprising, introducing said part in a liquid nitrogen medium to reduce the temperature of said part to the temperature of said medium, partially forming said part at said temperature to at least 10 percent of the total deformation required in forming said part, and thereafter finish forming said part at a temperature between about room temperature and 280° F.

4. The process defined in claim 3 wherein said finish forming operation is performed at about 260° F.

5. The process for forming a sheet metal part made of titanium comprising, introducing said part in a liquid nitrogen medium to reduce the temperature of said part to the temperature of said medium, partially bending said part at said temperature to at least 10 percent of the total bending required in forming said part, and thereafter finish bending said part at a temperature between about room temperature and 280° F.

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