RESEARCH OF HIGH-TEMPERATURE COMPRESSION PROPERTY OF TI2ALN/TIAL COMPOSITES

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Abstract

The reactive hot-pressing technique was used to fabricate TiAl alloy and Ti2AlN/TiAl composites with 20% volume fraction of Ti2AlN particles. The behavior of high-temperature compressive deformation and high-temperature mechanical property of TiAl alloy and 20Ti2AlN/TiAl composites under different temperatures and strain rates were studied. The feature of true stress-true strain curve and the relationship between high-temperature compressive strength and deformation parameters were analyzed. The mechanisms of hot compressive deformation and of strengthening of Ti2AlN/TiAl composites were revealed through this study. The results showed that the compressive strengths of TiAl alloy and Ti2AlN/TiAl composites with full lamellar microstructure decreased with temperature increasing, and increased with strain rates increasing; Compared with TiAl alloy, the increment of compressive strength of composites increased greatly at lower temperature and lower strain rates, and at higher temperature and higher strain rates; its maximum came up to 50% under the deformation conditions of 1100℃and 0.1s-1. Based on the strength of TiAl alloy, a three-dimension state graph of the relationship between the strengthening effect, the deformation temperature and the strain rate of composites was established.

1. Introduction

There are so many superior performances of TiAl intermetallic alloys, such as low density, good creep resistance, high specific strength and specific modulus, and high rigidity at high temperatures [1-5]. With the vigorous development of aerospace industry, the lightweight and high strength of alloys are demanded higher and higher to the high-temperature components, and TiAl matrix composites have attracted the attention of people more and more [6-8]. TiAl matrix alloys with the Ti_2AlN particles strengthening phase can improve the comprehensive performance of the composites. Researches about the high-temperature strength and the hot deformation behavior of Ti_2AlN/TiAl composites are rarely reported. The behavior of high-temperature compressive deformation and high-temperature mechanical property of TiAl alloy and 20Ti_2AlN/TiAl composites under different deformation temperatures and strain rates were studied in this paper. The change characteristics of the true stress - true strain curve, high-temperature compressive strength and microstructure were analyzed. The mechanisms of hot compressive deformation and of strengthening of Ti_2AlN/TiAl composites were attempted to reveal through this study.

2. Materials and experimental methods

In this paper, the reactive hot-pressing technique was used to fabricate TiAl alloy and Ti_2AlN/TiAl composites with 20% volume fraction of Ti_2AlN particles. The TiAl and Ti_2AlN/TiAl composites with prepared state were subjected to heat treatment in order to obtain full lamellar matrix organization. The sample was packaged by quartz glass tubes with the vacuum of 10^{-2} Pa; the temperature of the sample rose to 1380℃ with the furnace heating and kept this for 0.5 hours, then dropped with the furnace cooling.

Material etching solution is a mixture with ratio of 5%volHNO_3+5%volHF+90%volH_2O. The HITACHI S-570 scanning electron microscope was used for microstructure observation and composition determination. The phase composition of Composites was measured by X-ray diffractometer (D / MAX-RB-type), with scanning speed of 2deg/min and step of 0.02degree. Use PHILIPS CM12 TEM was used to analyze the microstructure of materials. Samples for TEM analysis were made by FIB.

TiAl alloy and 20Ti_2AlN/TiAl composites with full lamellar matrix microstructure were processed to Φ8 × 12mm cylinders as high-temperature compression samples; the test temperatures were: 1100℃, 1000℃, 900℃ and 800℃; the compression strain rates were: $0.001s^{-1}$, $0.01s^{-1}$ and $0.1s^{-1}$. Gleeble-1500D thermal simulation testing machine was applied in the high-temperature compression tests for the above materials.

In the test, the thermocouple was spot welded to the side surface of the cylindrical sample, and the ends of the sample and the pressure head of the test machine were coated by graphite powders as the lubricant to reduce the friction between the pressure head and the sample; the sample was heated by resistance heating method with heating rate of 10℃/s, and the test was started after keeping warm of 60 seconds.

3. Results and analysis

3.1. The true stress - true strain curve of hot compression

The true stress - true strain curve of Figure 1 and Figure 2 are obtained under different experimental conditions. The figure shows that the true stress - true strain curves of TiAl alloy and 20Ti_2AlN/TiAl composites have similar characteristics. With the true strain increasing, the flow stress increases; after reaching the peak (σ_p), the flow stress decreases, along with the gradually increasing of the strain.

When the compression temperature is above 1000 ℃, the limit strain of the two kinds of materials is larger, indicating that the hot machining deformation performance is better in this temperature range; but the material deformation performance is poor below 1000℃, and the materials break quickly after reaching the stress peak σ_p , almost no steady flow stage.

The true stress - strain curve of TiAl alloy shown in Figure 1, the compression strength of the alloy decreases as the temperature increases, and increases as the strain rate increases. At the same strain rate, the time of reaching the flow stress peak becomes shorter with the temperature increasing; that is to say the strain peak ε_p reduces. Temperature increasing, dislocation motion acceleration, recovery and sufficient polygonization process are helpful to reduce the dislocation density, so that the flow stress peak decreases. Strain rate increases, and the dislocation motion velocity gradually lags the strain rate, resulting in the dislocation density inside the sample increasing, so the flow stress increases.

Figure 2 is the true stress - true strain curve of 20Ti2AlN/TiAl composites at different temperatures and different strain rates. As the figure shows, the compressive strength of Ti_2AlN/TiAl composites is significantly higher than TiAl alloy at high temperature and high strain rate. It illustrates that the strengthening effect of Ti_2AlN particles is remarkable at high temperature and high strain rate. Ti_2AlN particles can hinder the recovery and the polygonization process of Ti_2AlN particles at high temperatures, namely, hindering the conduct of softening process.

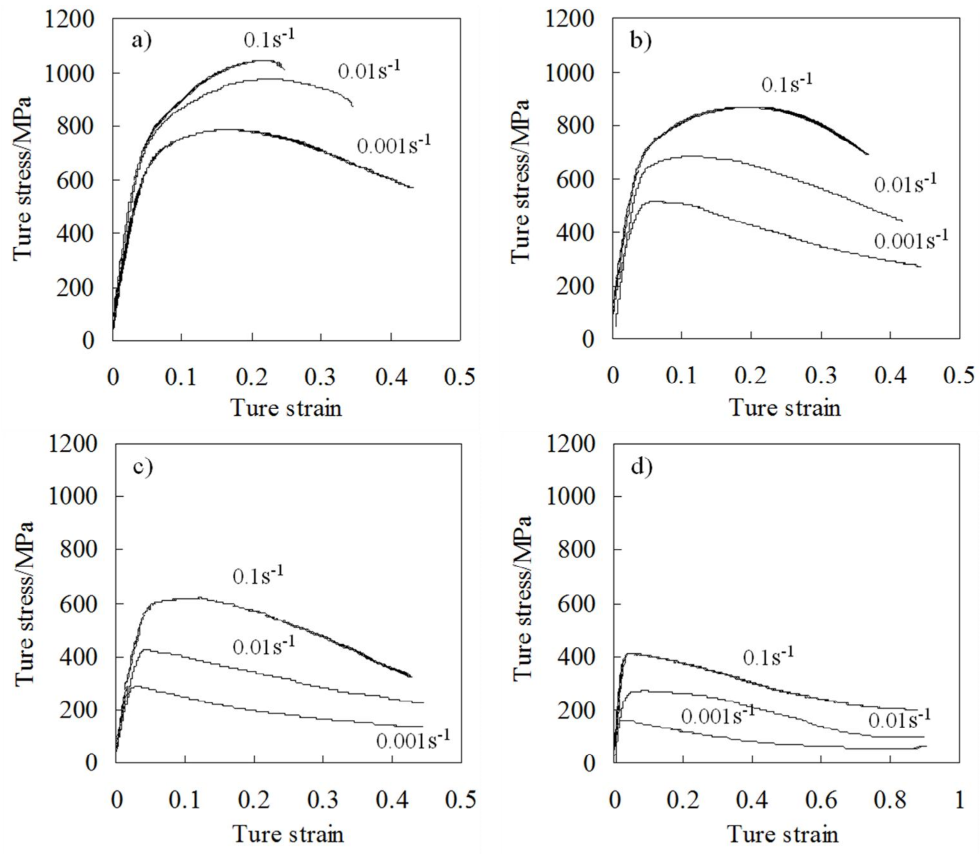

Figure 1. True stress-true strain curves of TiAl alloy compressed at different temperatures
a) 800℃, b) 900℃, c) 1000℃, d) 1100℃

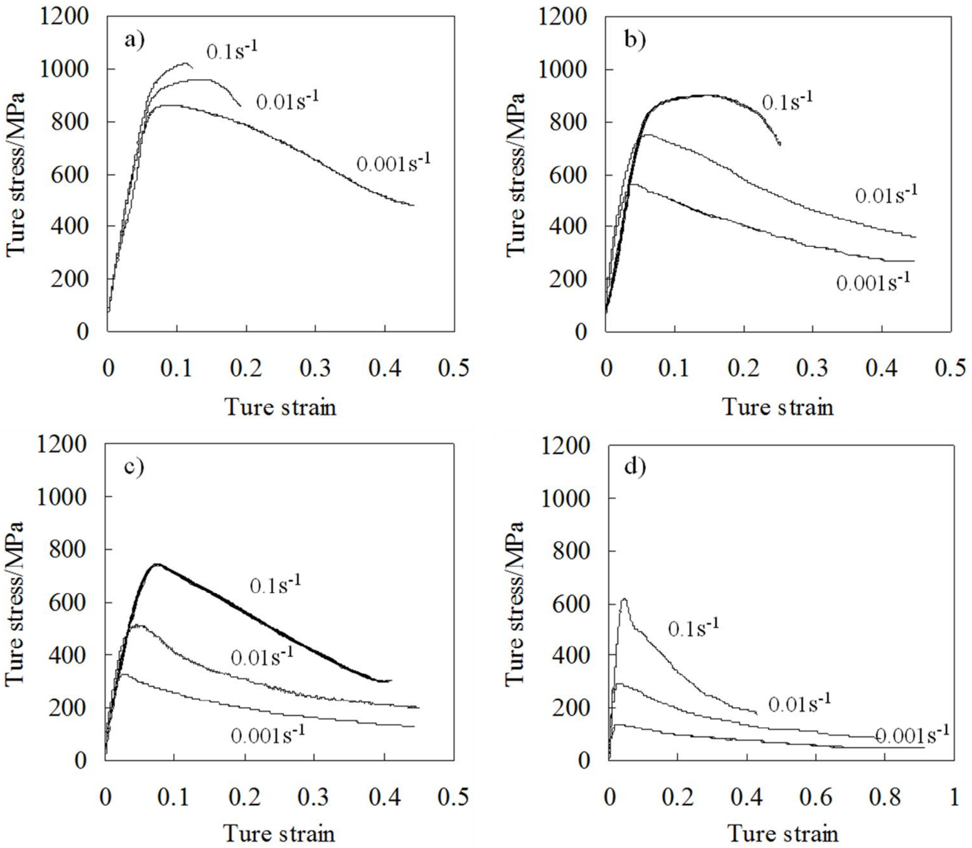

Figure 2. True stress-true strain curves of 20$Ti_2AlN/TiAl$ compressed at different temperatures
a) 800℃, b) 900℃, c) 1000℃, d) 1100℃

3.2. Influence factors of the compressive strength of Ti2AlN/TiAl composites

3.2.1.Influence of deformation temperature on compressive strength

The compression strength (i.e. the peak stress σ_p) of TiAl alloy and $Ti_2AlN/TiAl$ composites in experimental conditions are listed in Table 1, and the relationship curve between the compressive strength and temperature of two kinds of materials at the different strain rate is shown in Figure 3. From the figure it can be found that, at the same strain rate conditions, as the deformation temperature rises from 800 ℃ to 1100 ℃, the compressive strength of the composites decreases. The first reason is that the grain boundary strength decreases at high temperature, so the obstacle to the grain deformation weakens and the adjacent TiAl grains

Material	Temperature / ℃	Strain rate/ s^{-1}		
		0.001	0.01	0.1
TiAl	800	785.2	975.2	1045.2
	900	510.9	683.1	869.0
	1000	270.0	424.9	621.0
	1100	157.2	271.3	411.6
20$Ti_2AlN/TiAl$	800	861.5	958.6	1021.7
	900	564.8	748.8	900.3
	1000	325.3	515.1	742.6
	1100	152.5	293.8	618.4

Table 1. Compression strength of three kinds of materials at different conditions

are prone to slip; the second reason is that the dislocation inside the TiAl grains are easy to start, to slip and to climb at high temperatures, and the recovery and the polygonization occur, so the dislocation density decreases, leading to the material strength decreasing.
From Fig 3a) it can be seen that in the temperature ranging from 800 to 1100℃, at the same strain rate, the compressive strength of TiAl alloy significantly decreases with the temperature increasing; at different strain rates, the decreasing extent of the material strength is basically consistent with the temperature increasing. The strength - temperature curve of Ti2AlN/TiAl composites shown in Figure 3b), the compressive strength of the composites decreases significantly with the temperature rising at a lower strain rate ($0.01s^{-1}$ and $0.001s^{-1}$), while at the strain rate of $0.1s^{-1}$, the compressive strength decreases slowly with the deformation temperature increasing, which is due to Ti_2AlN reinforcement in the composite material bear some of the load and prevent the deformation process of the matrix.

At high strain rate, Ti2AlN particles as obstacles to dislocation motion will cause dislocation pileup and dislocation density increases, resulting the material strength of composites decreases gently with the temperature increasing.

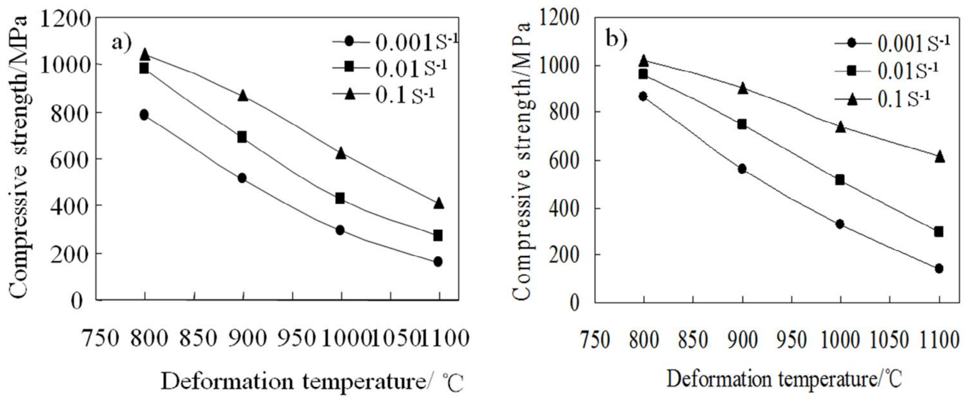

Figure 3. Influence of temperature to compressive strength

a) TiAl, b) $20Ti_2AlN/TiAl$

3.2.2. Influence of strain rate on compressive strength

The influence of the strain rate to the compressive strength of TiAl alloy and 20Ti2AlN/TiAl composites at different temperature is shown in Figure 4.

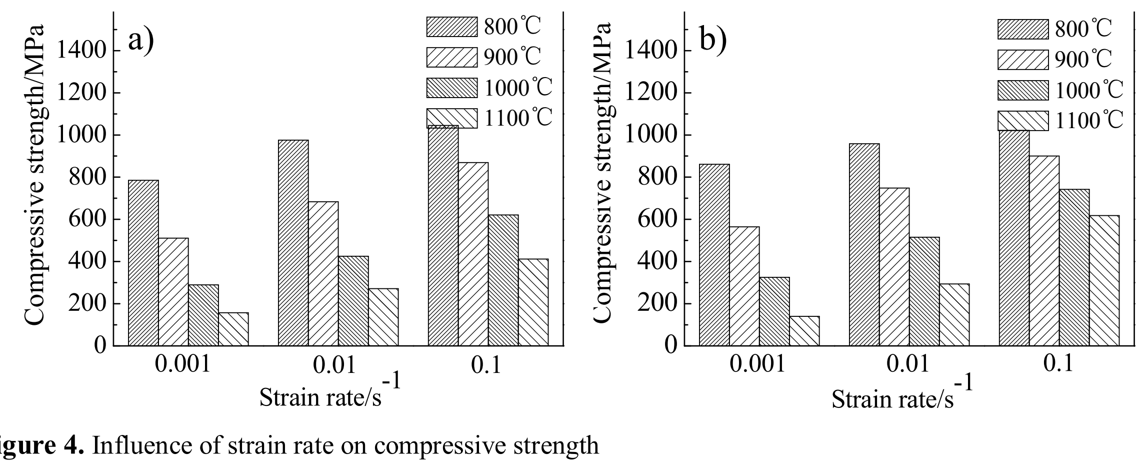

Figure 4. Influence of strain rate on compressive strength

a) TiAl, b) $20Ti_2AlN/TiAl$

Figure 4 shows that under the conditions with a certain temperature, the compressive strength of TiAl alloy and Ti2AlN/TiAl composites increase as the strain rates increases. These phenomena related to the dislocation movement speed when materials deform. As strain rate increases, the dislocation motion velocity is behind the deformation rate, and intragranular dislocation pileup goes up, and the resistance of dislocation motion increases; therefore, strength of materials rise. It also can be found from Figure 4 that when it deforms at the low-temperature range (800-900 ℃), the increase extent of the compressive strength of two materials is smaller, with the strain rate increasing; however, when it deforms at the high-temperature range (1000-1100 ℃), the increase extent of the compressive strength of two materials is larger, with the strain rate increasing; the cause of the phenomenon is related to the TiAl matrix softening and the bearer proportion of Ti2AlN particles increasing at high temperature.

3.2.3. Effect of Ti2AlN reinforcement on the composites strengthening

Taking the strength of TiAl alloy as a benchmark, the composites strength increasing of the relative amplitudes at different temperatures and strain rates are calculated, as shown in Table 2.

Ti2AlN volume fraction	Temperature /℃	Strain rate/s^{-1}		
		0.001	0.01	0.1
20%	800	9.7	-1.7	-2.2
	900	10.5	9.6	3.6
	1000	12.5	21.2	19.5
	1100	-10.6	8.2	50.2

Table 2. Compressive strength increased value (%) of composites relative to TiAl alloy
Note: A negative number indicates the strength of composites is less than TiAl alloys.

It can be found from Table 2 that under compression test conditions with the strain rate of $0.001s^{-1}$ and the temperature of 800℃, the compressive strength of composites is higher than TiAl matrix material about 10%; however, with the strain rate increasing, the strength of composites decreases, and it is lower than the matrix alloys., The compressive strength of composites increased significantly about 20% compared to TiAl matrix alloys at 900℃ and 1000℃. When it is compressed at 1100℃, the strength of $20Ti_2AlN/TiAl$ composites is less than TiAl alloy about 10% at low strain rate, because TiAl matrix, grain boundaries, matrix and reinforcement phase boundaries have begun to soften, and dislocation movement speeds, and the process of recovery speeds up, and the dislocation density declines, so the strength of composites is a little lower than TiAl alloy at high temperature. As the strain rate increases, the increase extent of strength of the composites increases, and is up to 50%. The main reason is Ti_2AlN reinforcement of $20Ti_2AlN/TiAl$ composites is particles and distributes in TiAl grain boundaries, which also can play a part in strengthening grain boundaries and impeding dislocation motion in low-temperature deformation, so its hot compressive strength increases, compared with TiAl alloys.

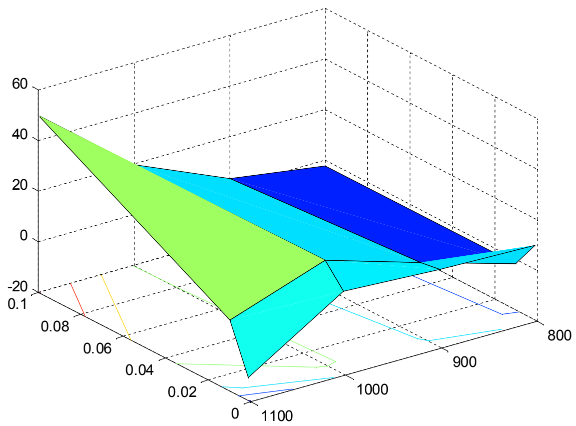

Figure 5. Influence of temperature and strain rate on increasement of strength $20Ti_2AlN/TiAl$ composites

Figure 5 is a three-dimensional surface map in which the increase extent of the compressive strength of $20Ti_2AlN/TiAl$ composites is compared with TiAl matrix alloys at different compression conditions. Observing the entire curved surface find the strength of composites is slightly lower than TiAl alloy at the low temperature with high strain rate and the high temperature with low strain rate, and, in other cases, the strength of the composites is always higher than TiAl alloys: in the range of 800-900℃, the increase extent of the strength of composites expands with the strain rate decreasing and the deformation temperature increasing; below 1000℃, at the same strain rate, the increase extent of strength goes up with the temperature rising; at the range of 1000-1100℃, the strength of the composites increases considerably in the region of high temperature and high strain rate and the region of low temperature and low strain rate; it is particularly worth noting below 1100℃ that the composites still keep the strength of 600MPa at the compression strain rate of $0.1s^{-1}$, which increases more than 50% , compared with 400MPa of the TiAl matrix alloys, and the superior performance of composites is very important to the application of materials at high temperature and high strain rate.

At low temperature, the high-temperature strengthening effect of composites is small, and the strain rate increases, but the high-temperature compressive strength of the composites has a downward trend compared with matrix alloys; temperature rising (to 1000℃), the strengthening effect of composites shows significantly, but with the strain rate increasing, the increase extent of strength weakens; during compression deformation at 1100℃ and low strain rate, the increase extent of strength of the composites is very low or even negative, but with the strain rate increasing, the increase extent of strength rises, and the increase extent of strength goes up to 50% at the strain rate of $0.1\ s^{-1}$.

4. Conclusions

(1) The compressive strengths of TiAl alloy and $Ti_2AlN/TiAl$ composites with full lamellar microstructure decreased with temperature increasing, and increased with strain rates increasing.

(2) Compared with TiAl alloy, the increment of compressive strength of composites increased greatly at lower temperature and lower strain rates and at higher temperature and higher strain rates; its maximum came up to 50% under the deformation conditions of 1100℃and $0.1s^{-1}$.

(3) Based on the strength of TiAl alloy, a three-dimensional state graph of the relationship between the strengthening effect, the deformation temperature and the strain rate of composites was established. The graph can be used to characterize the relationship between strengthening increment and hot deformation parameters of composites.

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