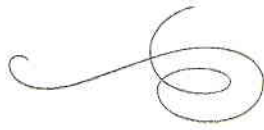
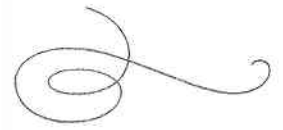


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*of Science and Useful Arts*

*The Director*

*of the United States Patent and Trademark Office has received an application for a patent for a new and useful invention. The title and description of the invention are enclosed. The requirements of law have been complied with, and it has been determined that a patent on the invention shall be granted under the law.*

*Therefore, this United States*

*Patent*

grants to the person(s) having title to this patent the right to exclude others from making, using, offering for sale, or selling the invention throughout the United States of America or importing the invention into the United States of America, and if the invention is a process, of the right to exclude others from using, offering for sale or selling throughout the United States of America, products made by that process, for the term set forth in 35 U.S.C. 154(a)(2) or (c)(1), subject to the payment of maintenance fees as provided by 35 U.S.C. 41(b). See the Maintenance Fee Notice on the inside of the cover.

*Andres Ibanez*

DIRECTOR OF THE UNITED STATES PATENT AND TRADEMARK OFFICE



US010006114B2

(12) **United States Patent**  
Nakahigashi et al.

(10) **Patent No.:** US 10,006,114 B2  
(45) **Date of Patent:** Jun. 26, 2018

(54) **TITANIUM ALLOY, METHOD OF MANUFACTURING HIGH-STRENGTH TITANIUM ALLOY, AND METHOD OF PROCESSING TITANIUM ALLOY**

(71) Applicants: **THE JAPAN RESEARCH INSTITUTE OF INDUSTRIAL SCIENCE**, Fukuyama-shi, Hiroshima (JP); **HONDA MOTOR CO., LTD.**, Tokyo (JP)

(72) Inventors: **Jun Nakahigashi**, Fukuyama (JP); **Kyo Takahashi**, Wako (JP)

(73) Assignees: **HONDA MOTOR CO., LTD.**, Tokyo (JP); **THE JAPAN RESEARCH INSTITUTE OF INDUSTRIAL SCIENCE**, Hiroshima (JP)

(\* ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 396 days.

(21) Appl. No.: **14/284,631**

(22) Filed: **May 22, 2014**

(65) **Prior Publication Data**  
US 2014/0356221 A1 Dec. 4, 2014

(30) **Foreign Application Priority Data**  
May 29, 2013 (JP) ..... 2013-112841

(51) **Int. Cl.**  
**C22F 1/18** (2006.01)  
**C22C 14/00** (2006.01)

(52) **U.S. Cl.**  
CPC ..... **C22F 1/183** (2013.01); **C22C 14/00** (2013.01)

(58) **Field of Classification Search**  
None  
See application file for complete search history.

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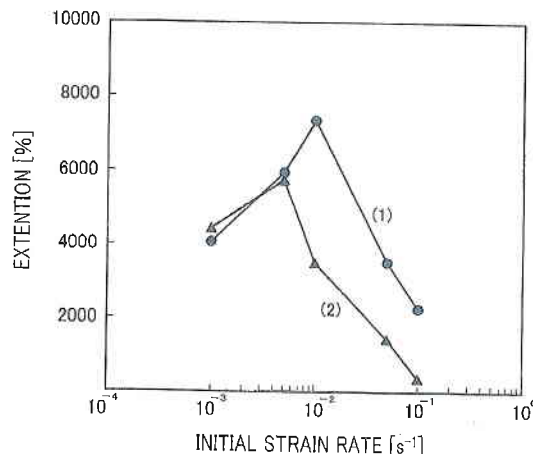
*Primary Examiner* — Colleen P Dunn  
*Assistant Examiner* — Nicholas A Wang

(74) *Attorney, Agent, or Firm* — Birch, Stewart, Kolasch & Birch, LLP

(57) **ABSTRACT**

Titanium alloy that is formed by subjecting titanium alloy to a treatment containing a hydrogen storing step for making the titanium alloy store hydrogen therein, a solution-treatment step for heating the titanium alloy having the hydrogen stored therein in the hydrogen storage step to apply a solution treatment to the hydrogen-stored titanium alloy, a cooling step for cooling the heated hydrogen-stored titanium alloy to develop martensitic transformation in the hydrogen-stored titanium alloy, a hot rolling step for heating the martensitic-transformed titanium alloy to a temperature which is not more than a predetermined transformation point and hot-rolling the martensitic-transformed titanium, and a dehydrogenation step for dehydrogenating the hot-rolled

(Continued)



titanium alloy, thereby bringing the titanium alloy with the superplastic property.

**16 Claims, 14 Drawing Sheets**

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FIG. 1

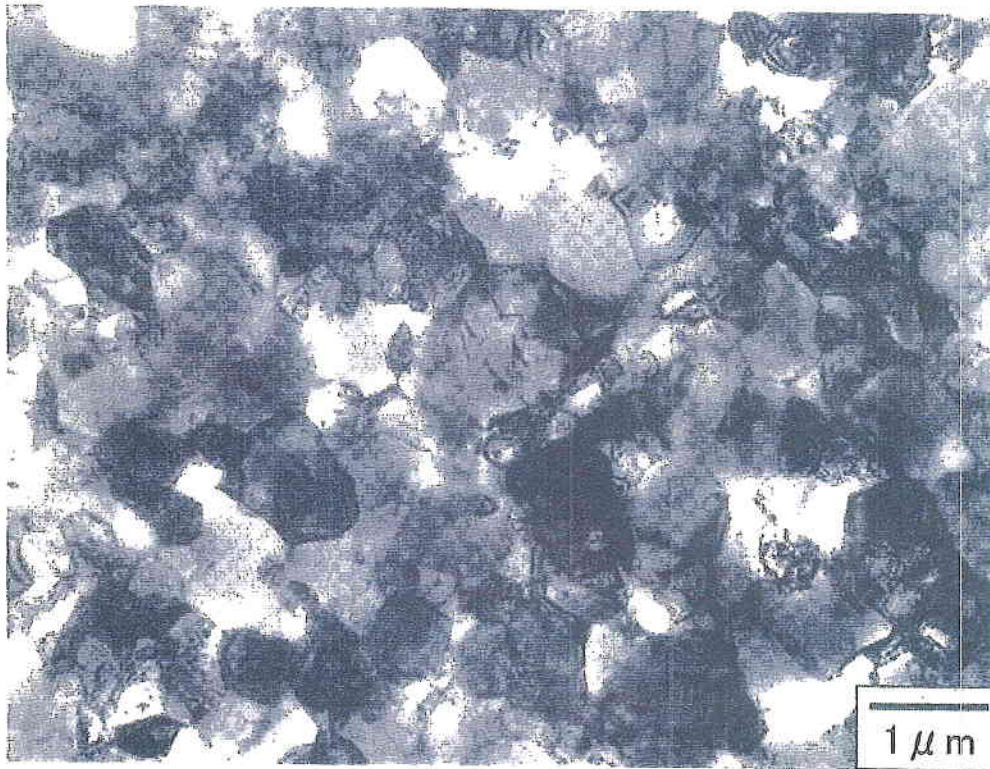


FIG. 2

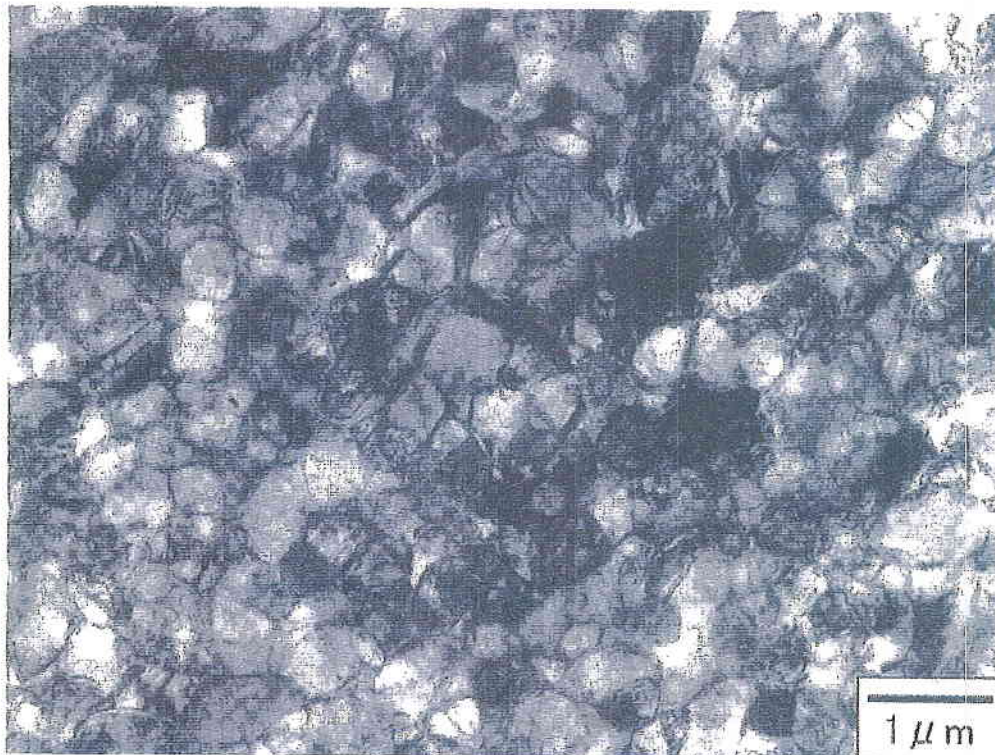


FIG. 3

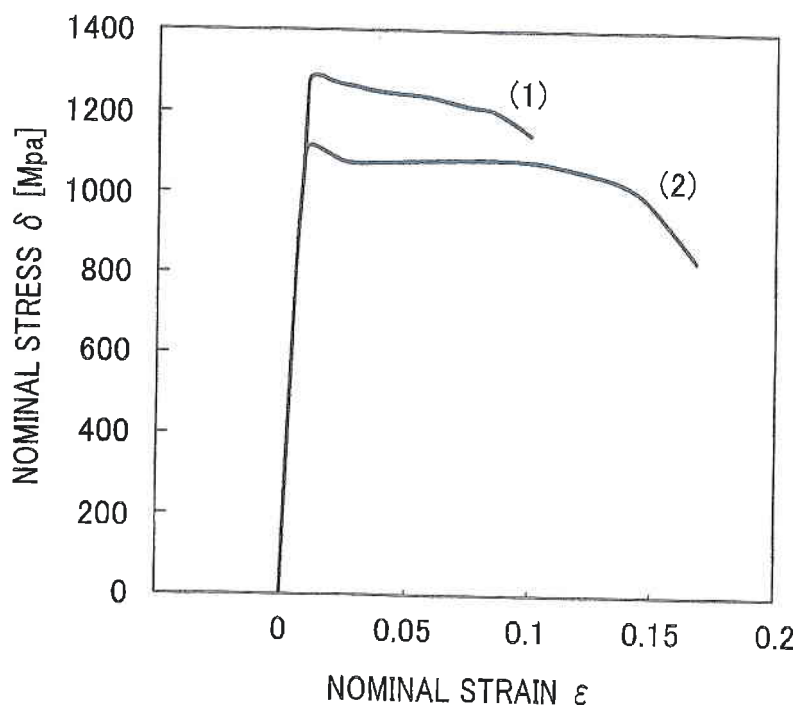


FIG. 4

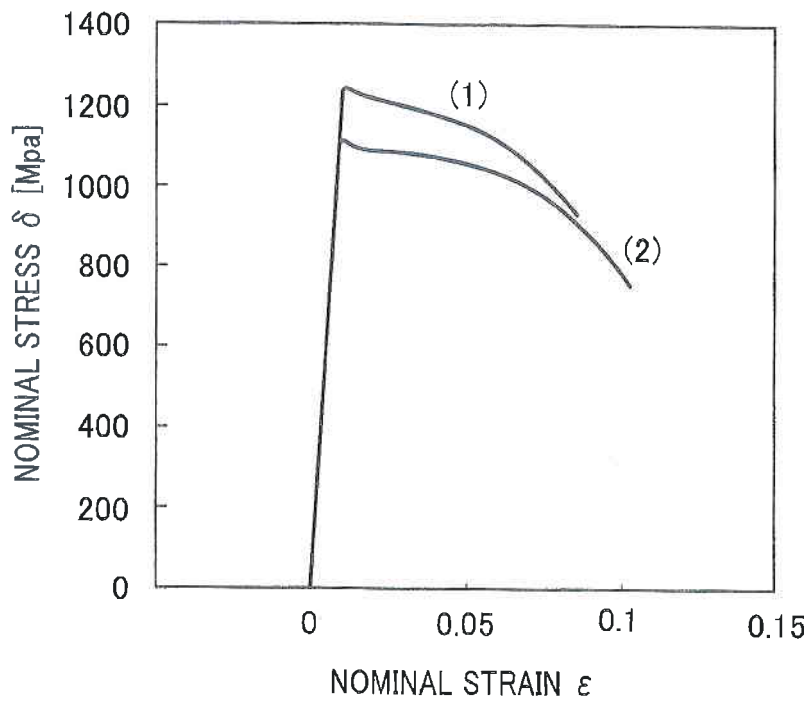


FIG.5

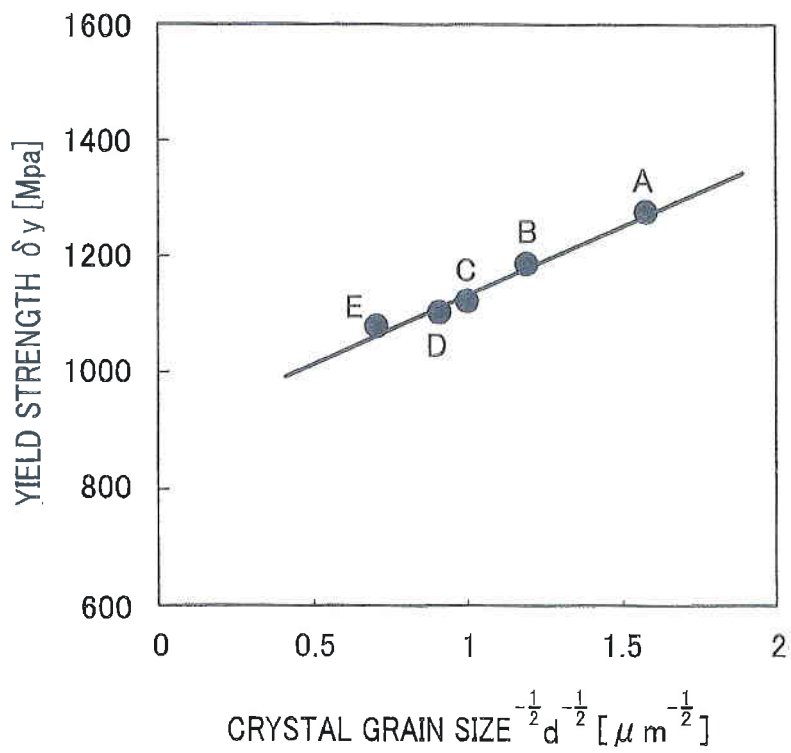


FIG. 6

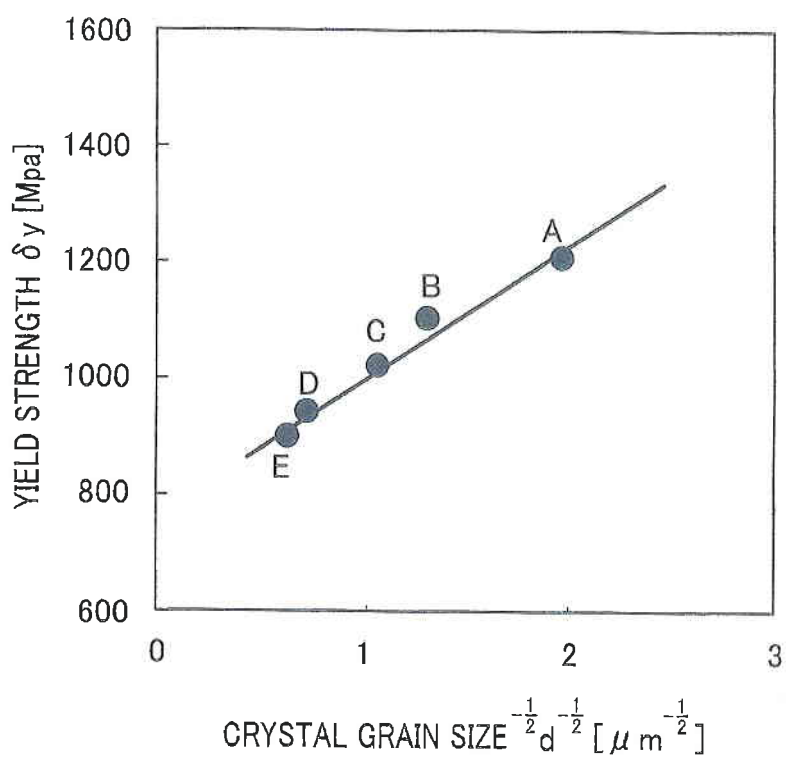




FIG. 7

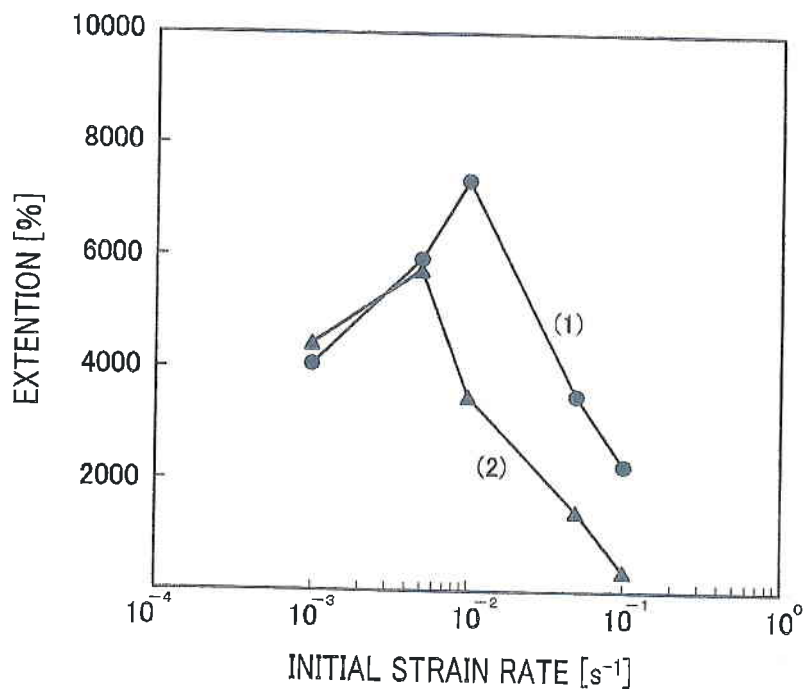


FIG. 8

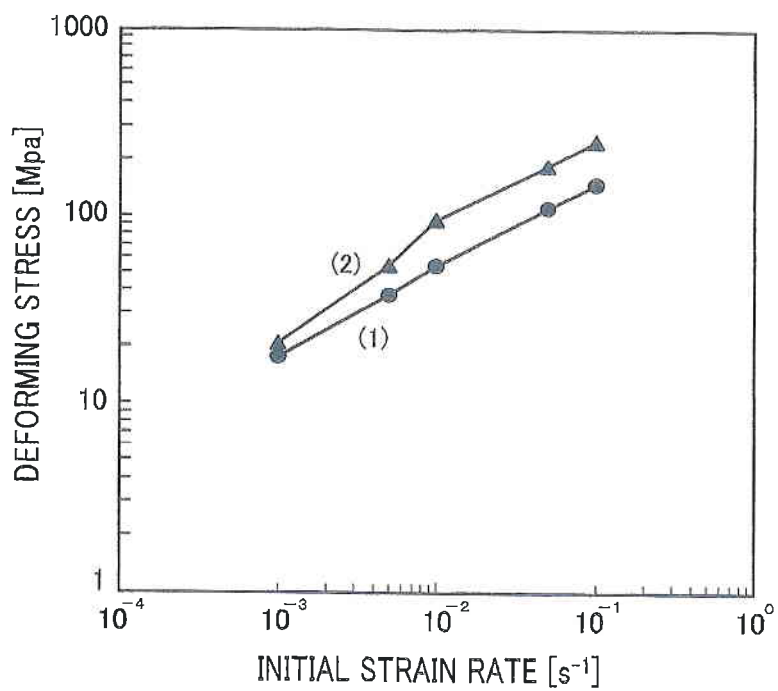


FIG. 9

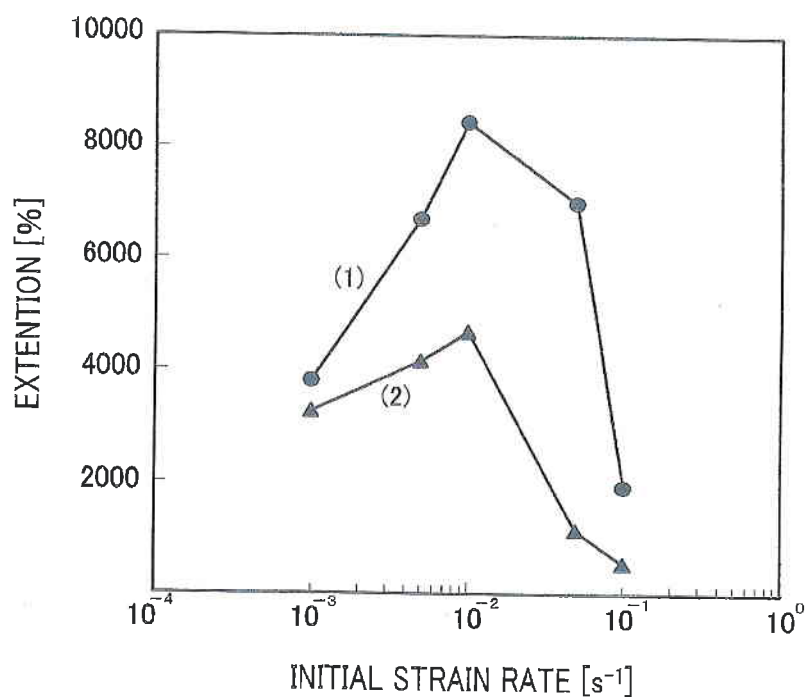


FIG. 10

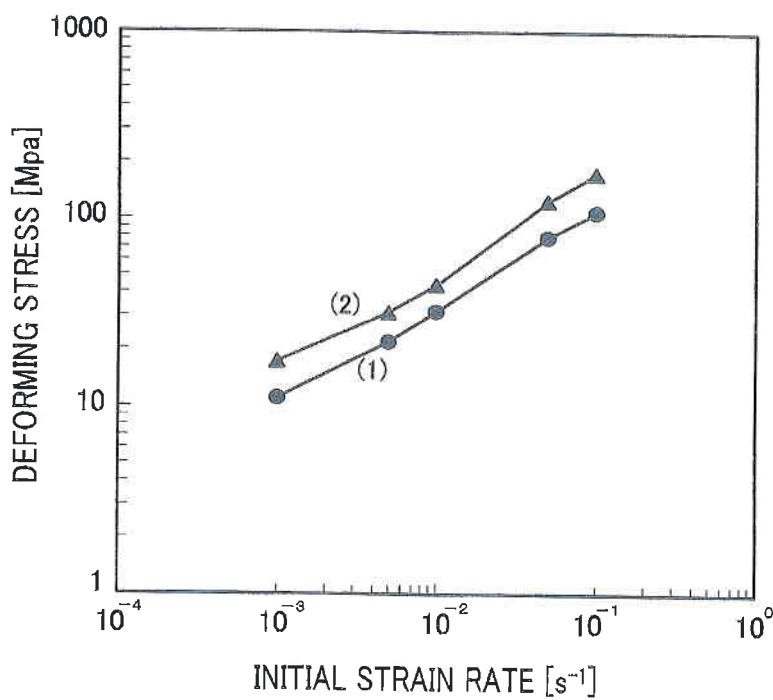


FIG. 11

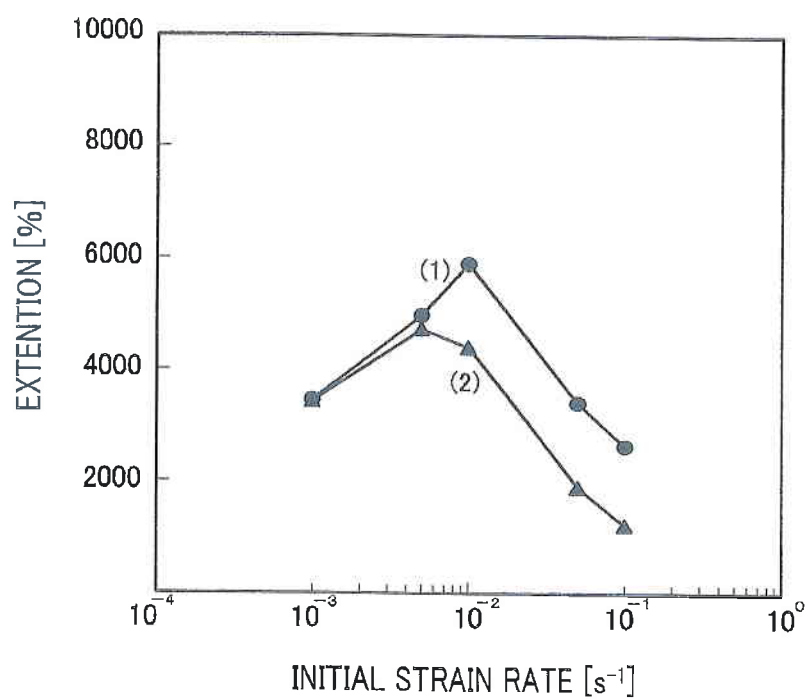


FIG. 12

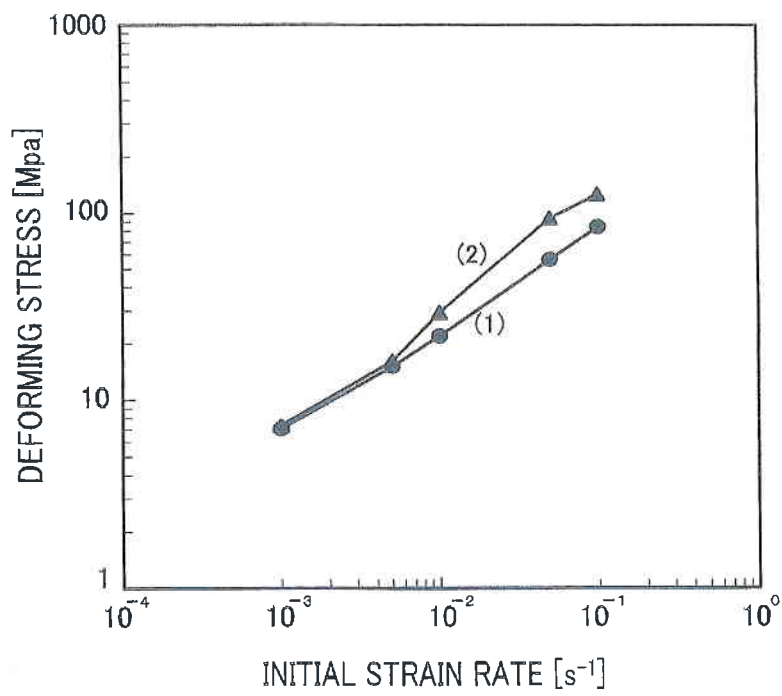


FIG. 13

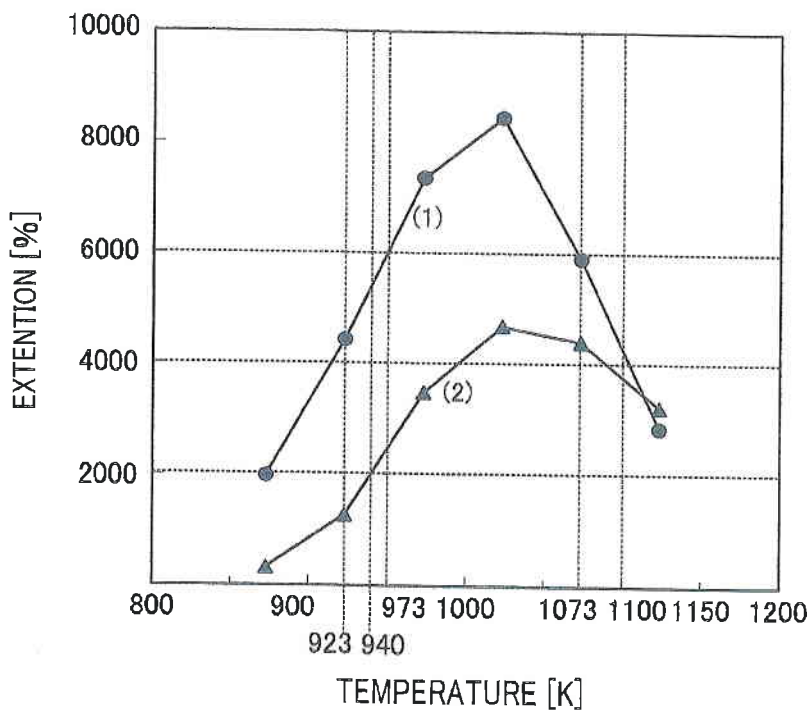
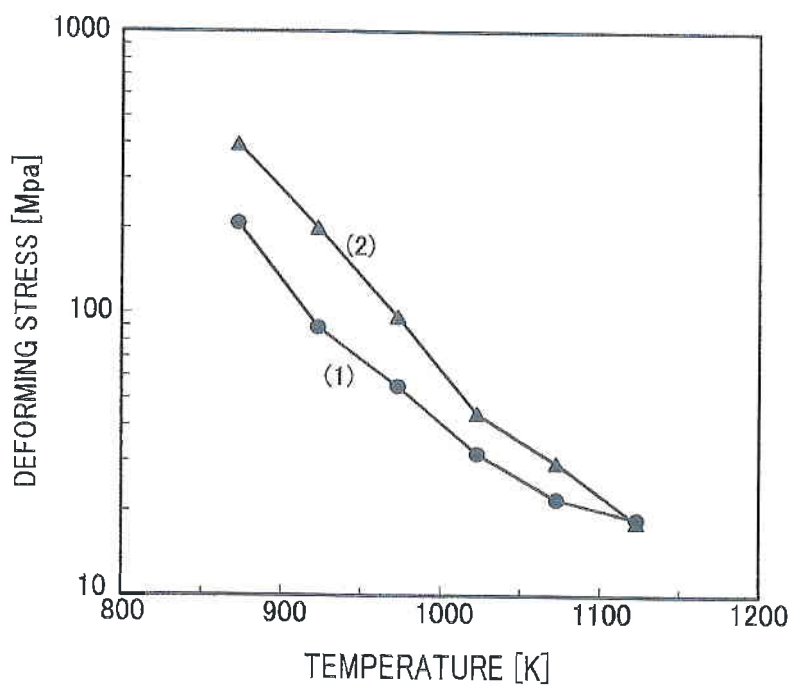


FIG. 14





### FIG.15A

TABLE 1

TEMPERATURE	MICRONIZED PARTICLE TITANIUM ALLOY (1)				ROUGH PARTICLE TITANIUM ALLOY (2)			
	STRAIN RATE	DEFORMING STRESS	EXTENSION	m VALUE	STRAIN RATE	DEFORMING STRESS	EXTENSION	m VALUE
973 K (700°C)	0.001	17.9	4050	0.47	0.001	21.2	4425	0.60
	0.005	38.3	5950	0.52	0.005	55.4	5750	0.81
	0.01	55.1	7350	0.44	0.01	97.3	3475	0.41
	0.05	112.6	3500	0.42	0.05	188.6	1425	0.44
	0.1	151	2250	—	0.1	256.1	363	—
1023 K (750°C)	0.001	11.0	3800	0.43	0.001	17.2	3250	0.37
	0.005	21.9	6700	0.54	0.005	31.4	4150	0.49
	0.01	31.8	8450	0.57	0.01	44	4675	0.64
	0.05	79.6	7000	0.45	0.05	124.1	1150	0.49
	0.1	108.4	1925	—	0.1	174	550	—
1073 K (800°C)	0.001	7.0	3450	0.47	0.001	7.28	3425	0.49
	0.005	15.0	4975	0.55	0.005	16.0	4725	0.88
	0.01	21.9	5900	0.59	0.01	29.39	4400	0.72
	0.05	56.2	3400	0.58	0.05	93.75	1900	0.42
	0.1	84.2	2625	—	0.1	125.66	1222.5	0.30
	0.5	—	—	—	0.5	204.1	300	—

### FIG.15B

TABLE 2

TEMPERATURE	MICRONIZED PARTICLE TITANIUM ALLOY (1)		ROUGH PARTICLE TITANIUM ALLOY (2)	
	DEFORMING STRESS	EXTENSION	DEFORMING STRESS	EXTENSION
873 K (600°C)	208.2	1975	397	325
923 K (650°C)	89.1	4425	200	1275
973 K (700°C)	55.1	7350	97.3	3475
1023 K (750°C)	31.8	8450	44	4675
1073 K (800°C)	21.9	5900	29.39	4400
1123 K (850°C)	18.6	2850	18.2	3225