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Fuel Pin Behavior During UO_2 Pellet Melting

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Fuel pin behavior with heat rating up to UO_2 melting was investigated by means of power cycling capsule of JMTR (Japan Materials Testing Reactor). The fuel pin was subjected to power irradiation examination for metallographic study. Results are:

(1) UO_2 pellet melting occurred at 630 W/cm and the molten UO_2 spread cylindrically in one-third the bulk of specimen.
(2) A typical cross sectional ceramography revealed that grain boundaries were not observed at the central part and non-equiaxial and equiaxial grains were observed at middle and outer parts.
(3) Pores were mostly on the grain boundaries, few in the grains.
(4) Cracks in the pellet were transgranular.

Keywords: Fuel Pin, Uranium Dioxide Pellet, Axial Driven Power Cycle Apparatus, Melting, Grain Boundary, Crack Propagation, Irradiation Examination, Elongation.

UO_2ペレット溶融時の燃料ピンの挙動

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縦駆動照射装置の特性を利用してUO_2ペレット溶融時の燃料ピンの挙動を金相観察によって調べた。得た結論は以下の通りである。

(1) UO_2ペレットの溶融は約６３０W/cm で生じ溶融域は同心円状に試料全体の $1/3$ まで広がった。

(2) 典型的なペレットの横断面形態を金属写真を用いて観察した結果，ペレット中心部では粒界が見られず中間および外縁部で非等軸および等軸粒が生じていた。

(3) 殆んどの気孔は粒界内側でなく粒界上に集積していた。

(4) ペレットの割れの形態は粒内割れであった。

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1. Introduction

The characteristics of axial driven irradiation apparatus is described in a published paper(1). This paper will describe " Fuel Pin Behavior During UO_2 Pellet Melting" by utilizing that apparatus.

The primary objective of this paper is to describe above phenomena by means of photomicrograph after irradiation.

2. Irradiation Condition

2.1. Materials used for irradiation

Specifications of fuel and of clad used in the experiment are:

—— Fuel

Material	:	UO_2 pellet
Density	:	92.6%TD
Outer Diameter	:	15.01 mm
Enrichment	:	2.6 w/o

—— Clad

Material	:	AISI-316
Inner Diameter	:	15.12 mm
Diametral Gap	:	110 μm

W/W-Re thermocouple and FP gas pressure measuring sensor were attached to the fuel pin.

2.2. Capsule

Axial driven power capsule was manufactured in JAERI.The capsule is composed double tubes with NaK as cooling materials between the tubes.AISI-304 and -316 were used as tube materials.

2.3. Irradiation history

Irradiation under constant power level (LHR) of nearly 400-450 W/cm (estimated) was performed on 33th cycle in JMTR. At the end of the irradiation, power ramping was performed up to the linear heat rate of nearly 630 W/cm. Pellet temperature was recorded successively up to about 1700 degree at the

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3. Post-Irradiation Experiment

3.1. X-ray inspection

X-ray inspection traces in the direction of A and B are shown in Fig. 1(a). From the observation upper pellet deformation at the end position was found in both directions. Schmatic sketch of the closeup was shown in Fig.1(b). From the figure, it was seen that a chipped fragment of the top pellet of about 2 mm long was situated the top of fuel pellet.

3.2. Metallographic observations

After power ramping and fuel rod quenching operation, fuel pin was dismounted from the capsule and two metallographic specimens were prepared; one for cross sectional and longitudinal observation as shown in Fig.2.

Metallography of both specimens were shown in Fig.3 and Fig.4. The result obtained from metallography are as follows:

(1) UO_2 pellet melting was apparently occurred during power ramping up to nearly 630 W/cm (estimated linear heat rating).

(2) Homogeneous and cylindrical melting occurred in about one-third of the radious.

(3) At the centre of the UO_2 pellet grain boundary disappeared perfectly and non-equiaxial and equiaxial grain formation occurred in outer and middle region.

(4) Grain size measurement was performed for the both specimens using two-dimensional,intercept procedure(2), and multiplication factor of 1.2 was used to convert from two to three dimensional counting. The result is shown on Table 1. From the measurement, grain diameter of 27 μm was obtained both in cross-sectional and longitudinal parts.

From the grain size measurements it was concluded that grain growth did not occurred homogeneously in both parts. It seemed thermocouple tip. Inner pressure of fuel pin, however , could not be measured.

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(5) Neglecting the small amount of pores in the grains, pore accumulation occurred mostly on the grain boundary. On the other hand, lenticular pores were observed at the pellet centre. Comparing pore size in the middle and the outer part of the pellets, it was observed that the pore size in middle seemed to be smaller than those of the outer ones due to radial or axial difference of temperature distribution.

(6) Crack morphology revealed that transgranular cracking occurred when cracks propagated over the pellets.

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References

(1) K.YANAGISAWA:"FuelPin Deformation Measurement Under Power Cycle Operation" JAERI-M (1978)

(2) K.YANAGISAWA: " Conception,Definition,Measuring Procedure of Grain Size" JAERI-M 6839 (1976)

Acknowledgement

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Appendix

Statistical Testing Introduced in This Paper .

(1) $2\sqrt{N}$ Test

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Difference=9-7=2

Sum =9+7=16

Twice square-root sum = $2\sqrt{16}$

= 8

Difference is now mucn smaller than twice square-root sum then there is not significant.

(2) Turkey Test

More than 26 (the highest value in traverse) in Longitudinal

2

Less than 17 (the lowest value in londitudinal) in traverse

0

The sum 2+0 = 2 < 7

The difference between two sets of result is not significant.

Grain Size

Transeversal:

(50mm/22.1counts)* (1000/100)*(1.2) = 27 μm.

(Intercept) *(Scale change)*(Converting factor)

Londitudinal:

(50mm/22.4counts)*(1000/100)*(1.2) = 27 μm.

Grain diameter of both directions are equivalent.

Table 1. Result of Grain Size Measurement

	Transverse	Londitudinal	
	22	19	−
	21	19	−
	22	17	−
	26	21	−
	21	26	+
	18	27	+
	22	28	+
	19	24	+
	20	24	+
	19	23	+
	25	26	+
	20	19	−
	24	18	−
	24	23	−
	26	25	−
	25	20	−
Average:	22.1	22.4	

Counted by Intercept procedure with a 50 mm circular plate

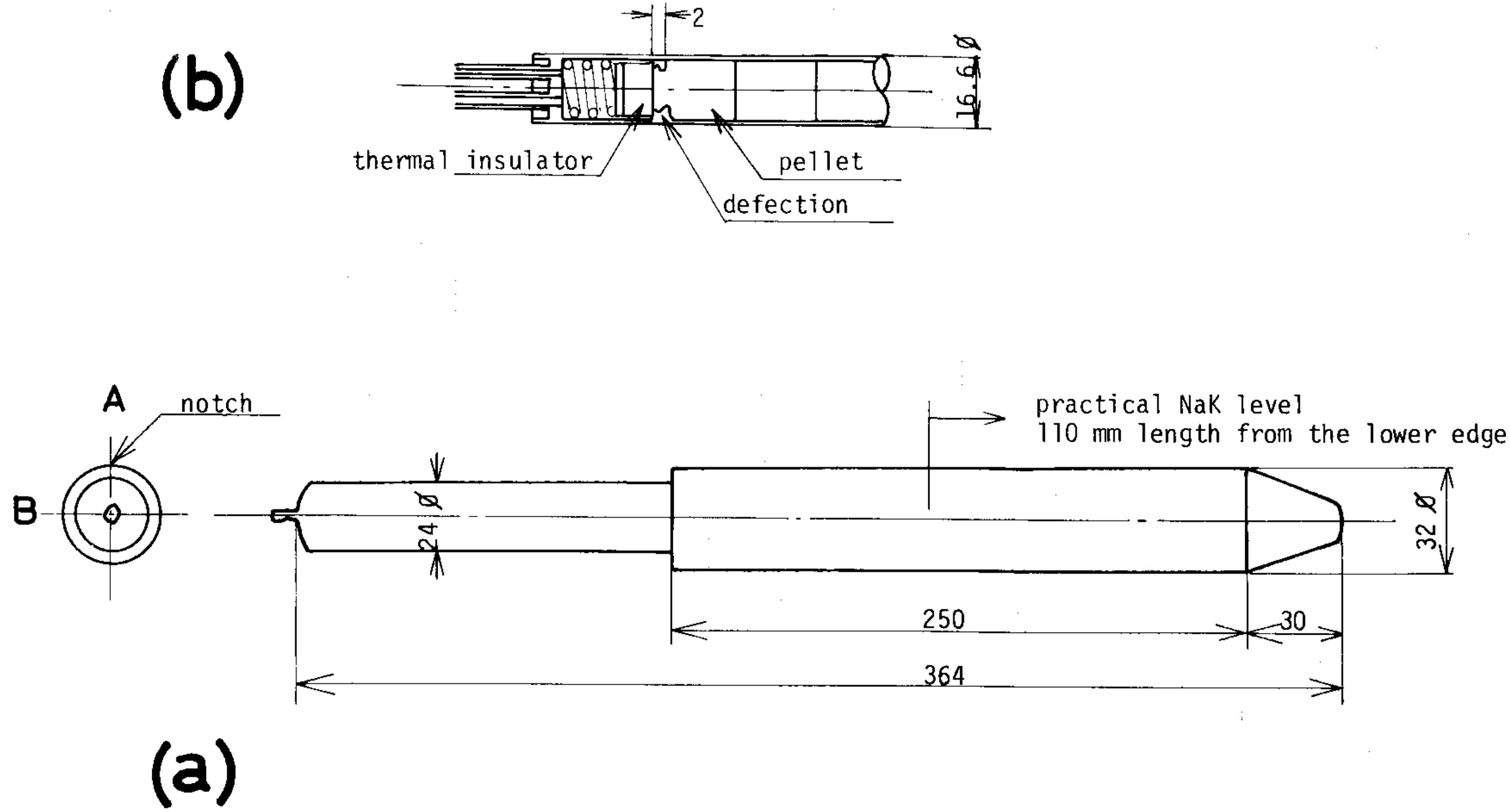

Fig. 1. (a): X-ray inspection traces in the direction of A and B, (b):schematic sketch of the closeup of the capsule

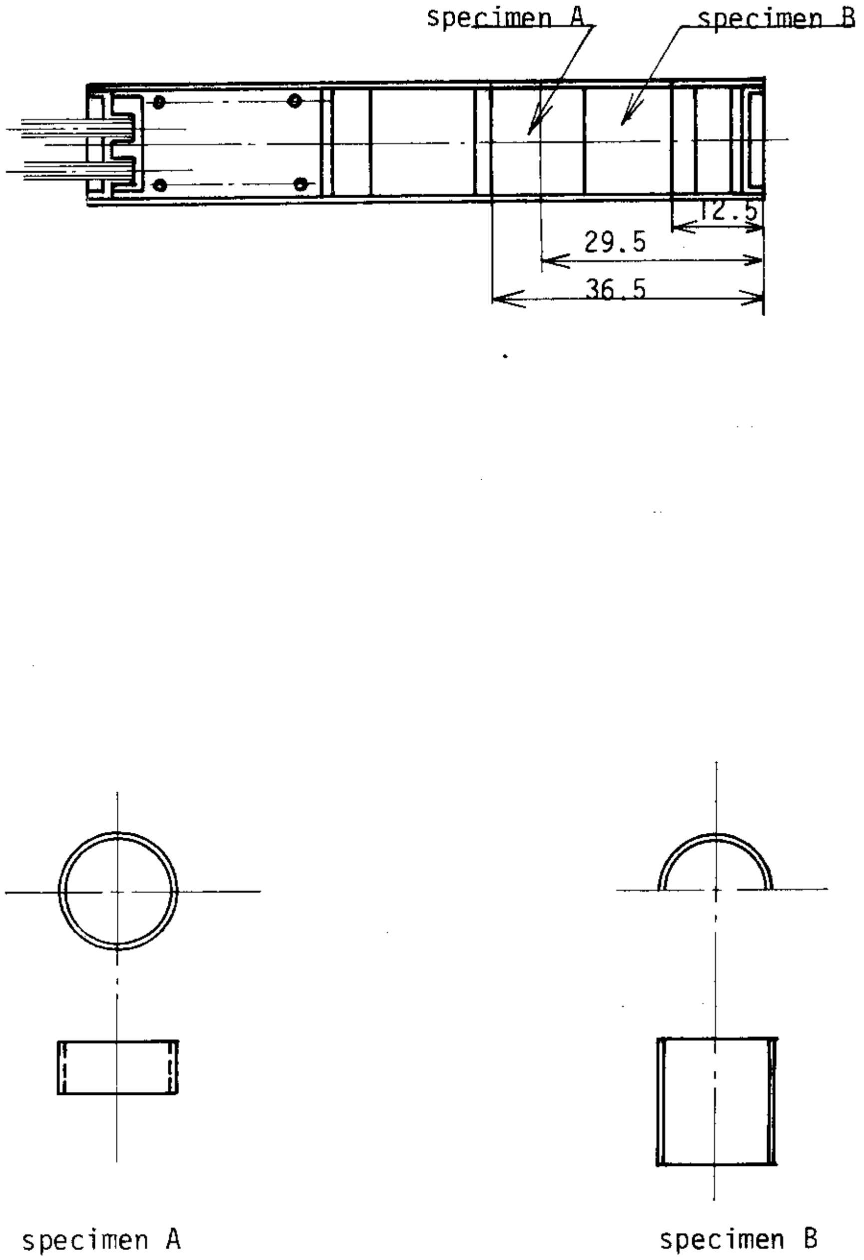

Fig. 2. Schematic drawing of a fuel pin dismounted from the irradiation capsule

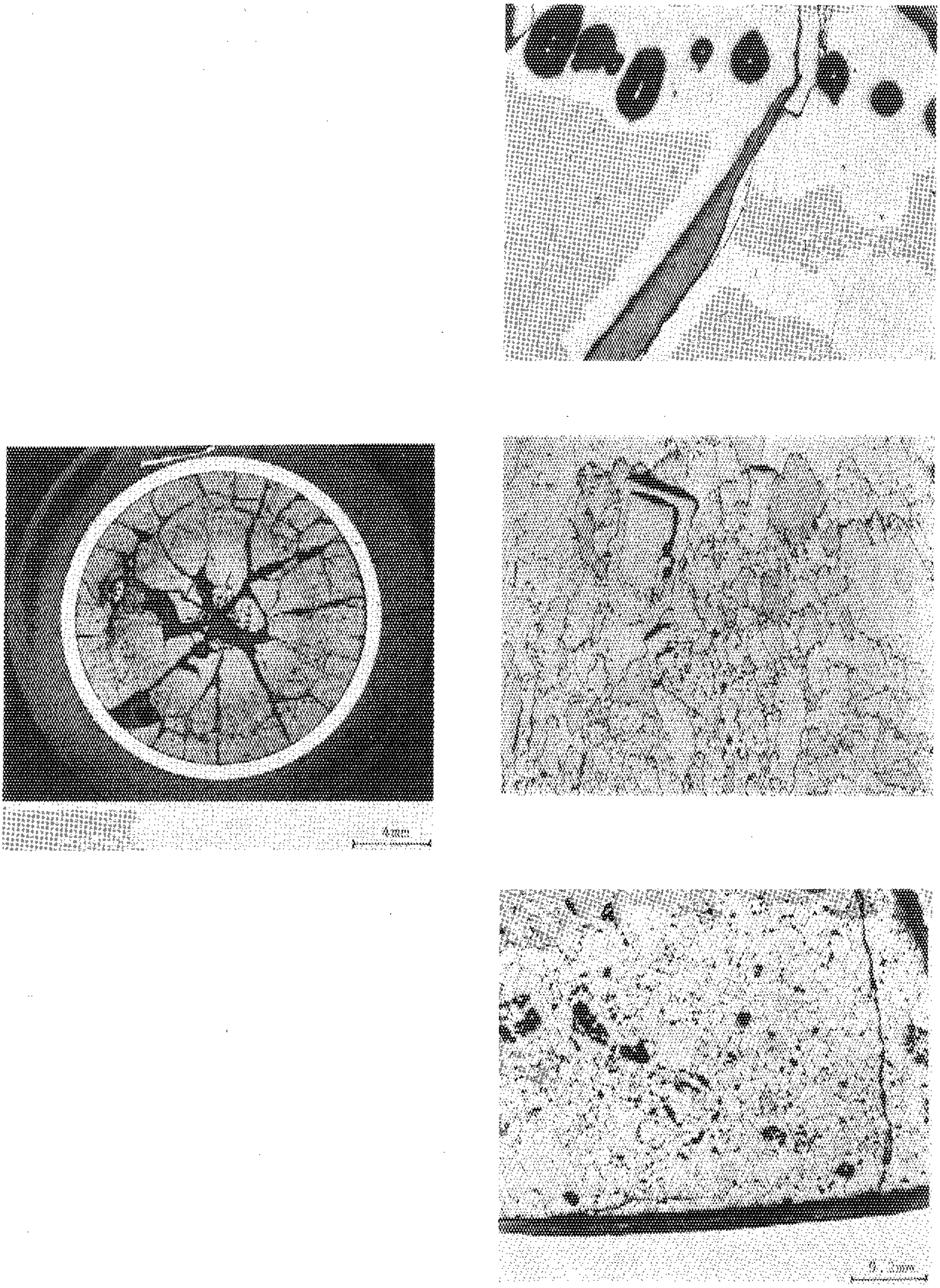

Fig. 3.   Photomicrograph of a transversal cross section

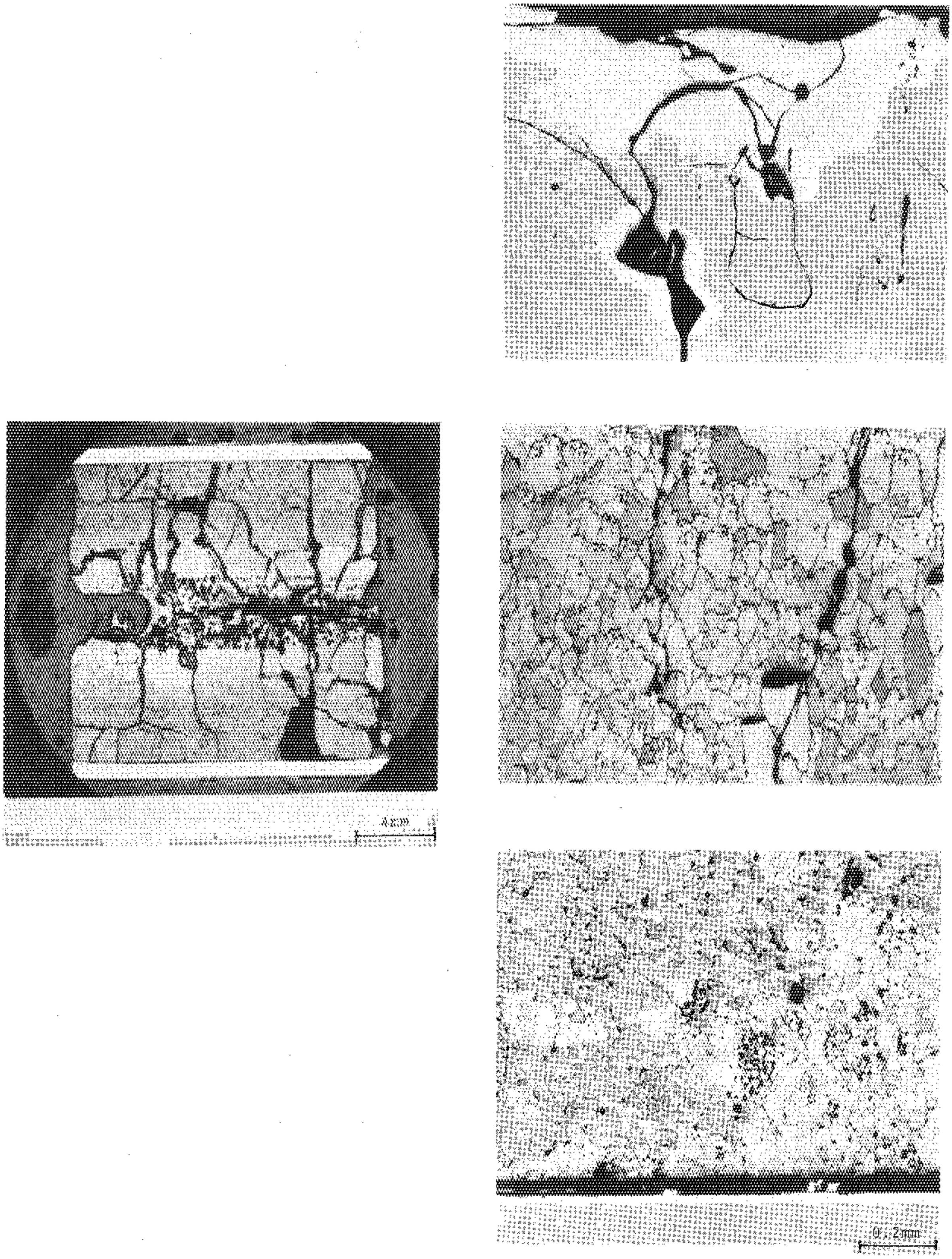

Fig. 4. Photomicrograph of a longitudinal cross section