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(19) **United States**(12) **Patent Application Publication**  
Fukuhara et al.(10) **Pub. No.: US 2007/0071630 A1**(43) **Pub. Date: Mar. 29, 2007**(54) **WEAR-RESISTANT ELEMENTS AND  
METHOD OF MAKING SAME**(30) **Foreign Application Priority Data**(76) Inventors: **Hiroyuki Fukuhara**, Shiga (JP); **Kenji Sasaki**, Shiga (JP); **Kensuke Hirata**, Kanagawa (JP); **Toshihiko Homma**, Kanagawa (JP)

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A material is shaped and sintered into a compact using iron-based alloy powder containing Cr; and a nitriding treatment having no carburizing action is conducted to the compact so that a surface of the compact may have a mixed structure 3 of an Fe—Cr—N compound layer 2, an Fe—Cr—N diffused layer, and a matrix.

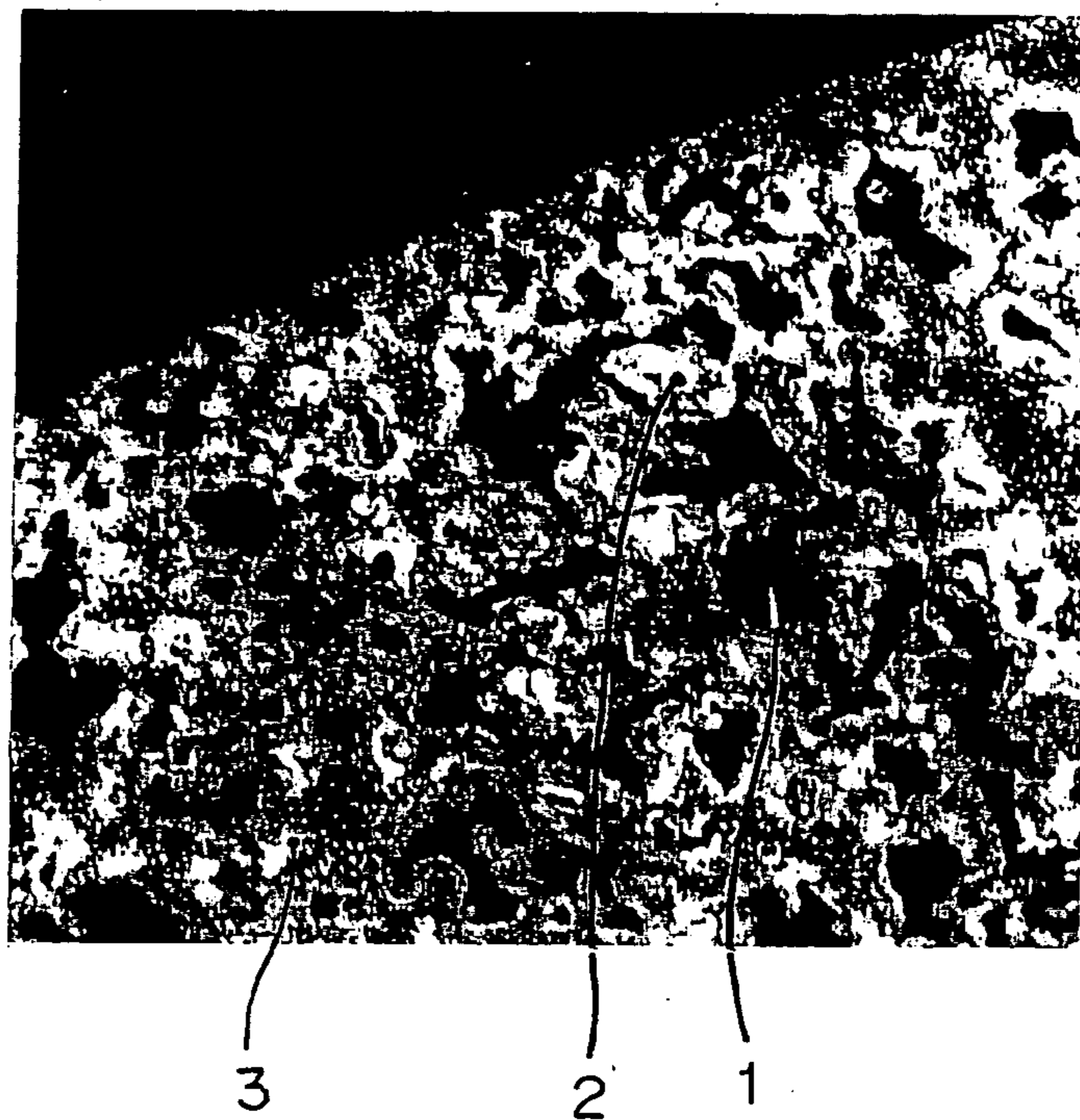
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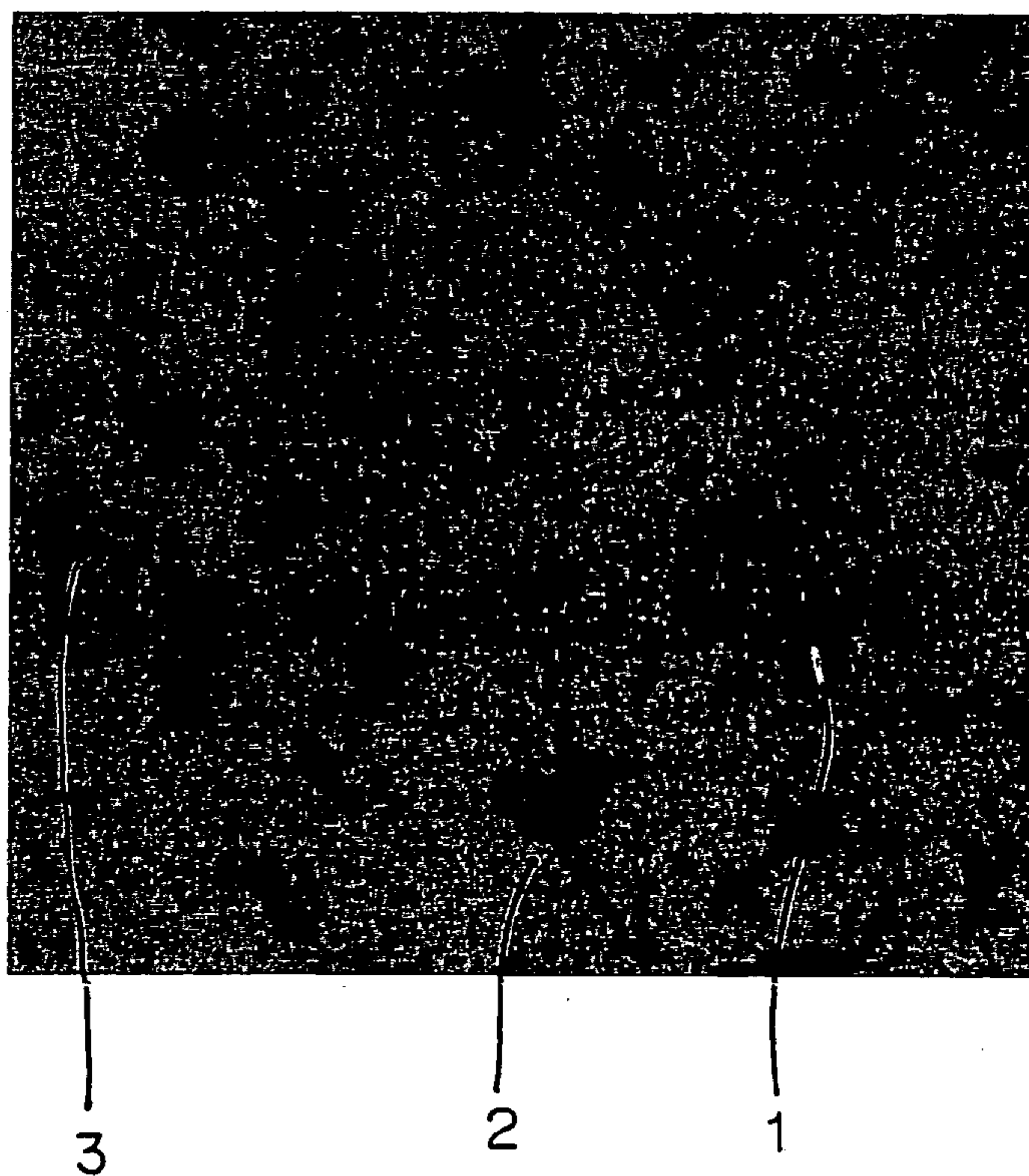
(2), (4) Date: **Apr. 20, 2006**

SAMPLE X	VACUUM 1180°C × 1.0H SINTERING BATCH FURNACE ROOM TEMP GAS COOLING	CARBURIZING ATMOSPHERE 870°C × 1.0H ROOM TEMP QUENCHING CONTINUOUS FURNACE OIL QUENCH	ATMOSPHERE 480°C × 1.5H TEMPERING
	POWDER BONDING	MARTENSITIZING OF MATRIX	DECOMPOSITION OF REMAINING $\gamma$ /RELAXATION OF QUENCHING DISTORTION
SAMPLE Y SAMPLE Z	VACUUM 1180°C × 1.0H ROOM TEMP SINTERING BATCH FURNACE GAS QUENCHING	NON-OXYGEN (NITROGEN) ATMOSPHERE	NON-OXYGEN (NITROGEN) ATMOSPHERE 580°C × 1.5H TEMPERING 580°C × 1.5H TEMPERING
	POWDER BONDING + MARTENSITIZING OF MATRIX		DECOMPOSITION OF REMAINING $\gamma$ /RELAXATION OF QUENCHING DISTORTION
	SINTERING	QUENCHING	TEMPERING

*Fig. 1*



*Fig. 2*





*Fig. 3*

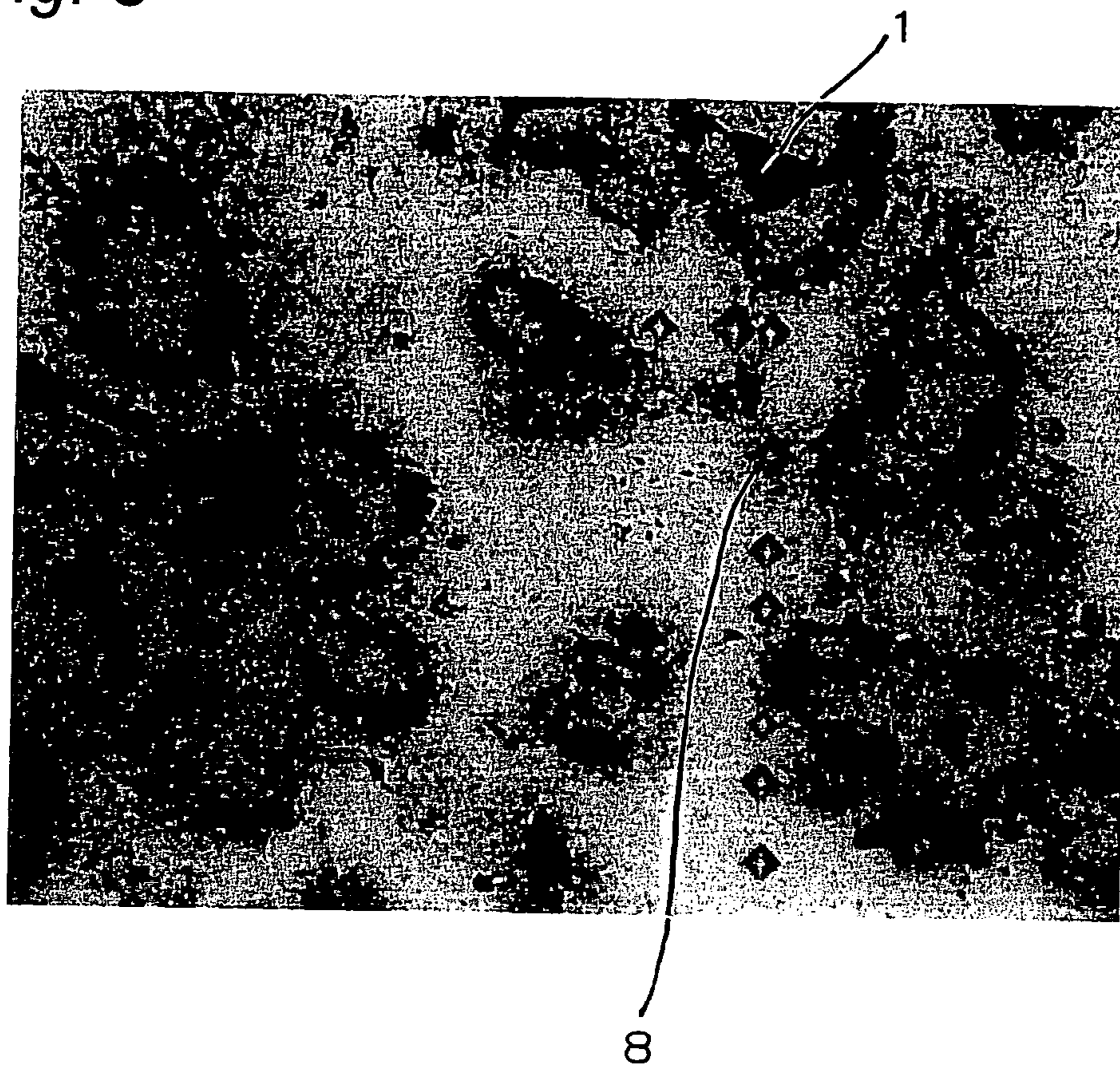


Fig. 4

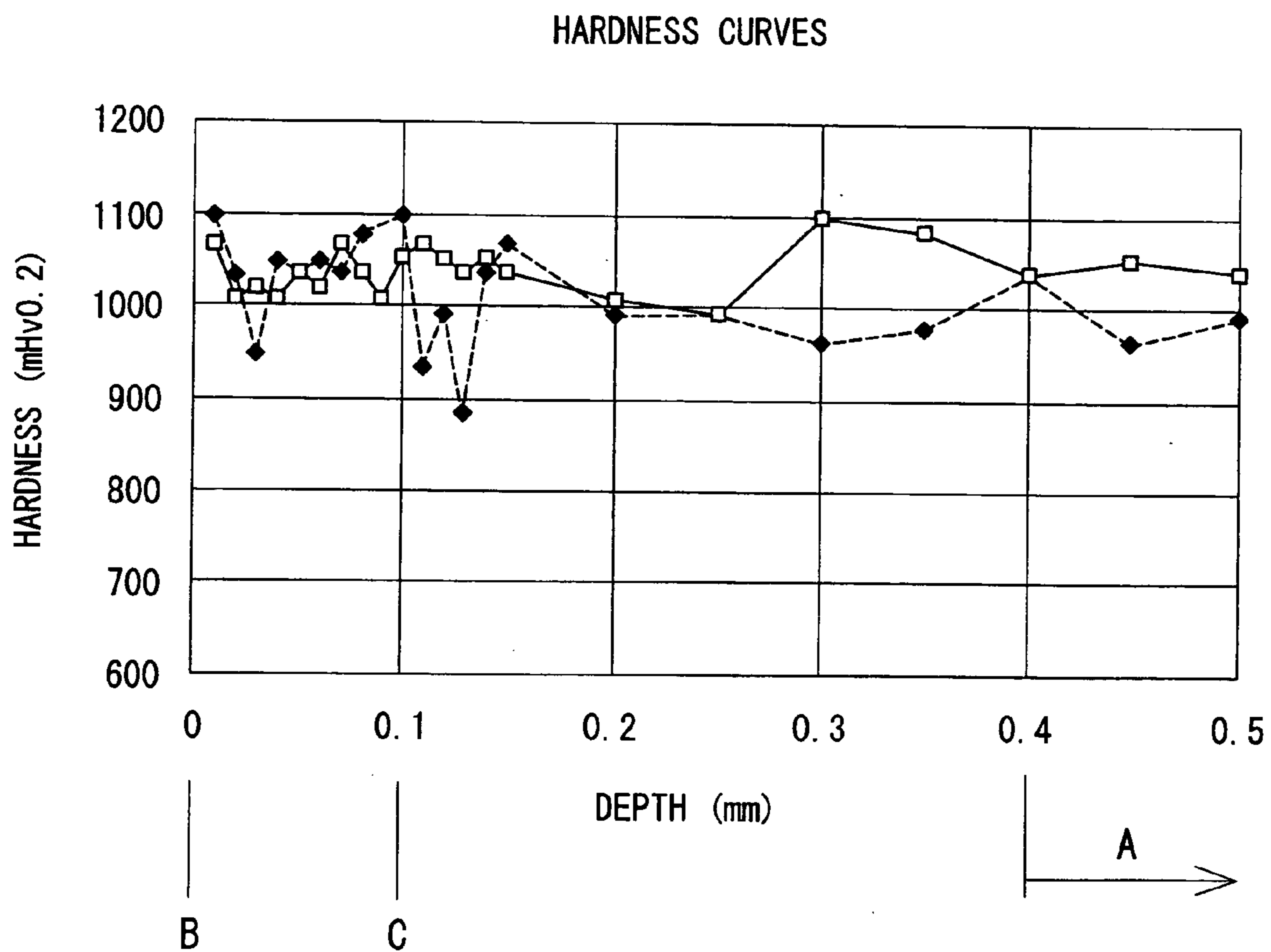
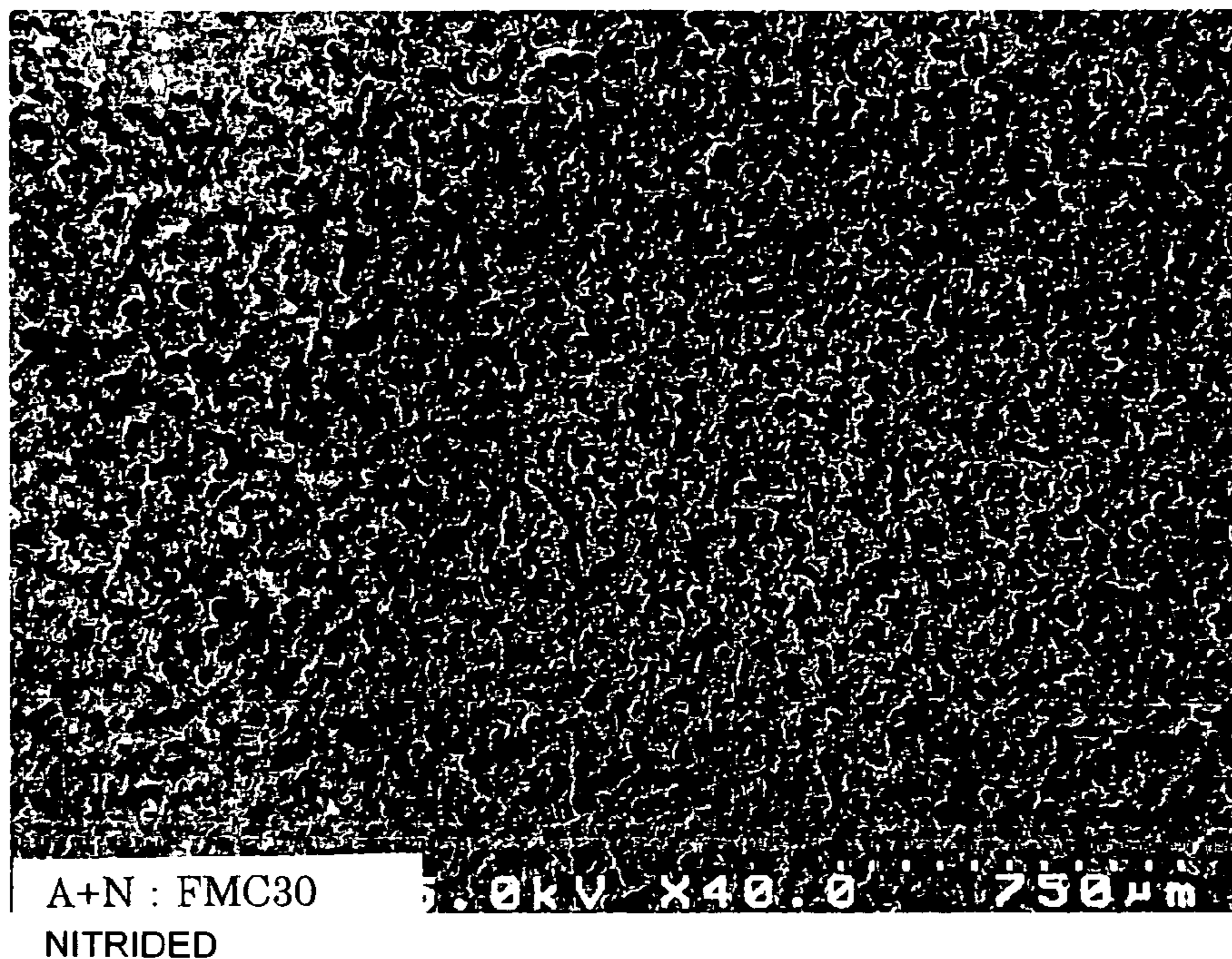


Fig. 5

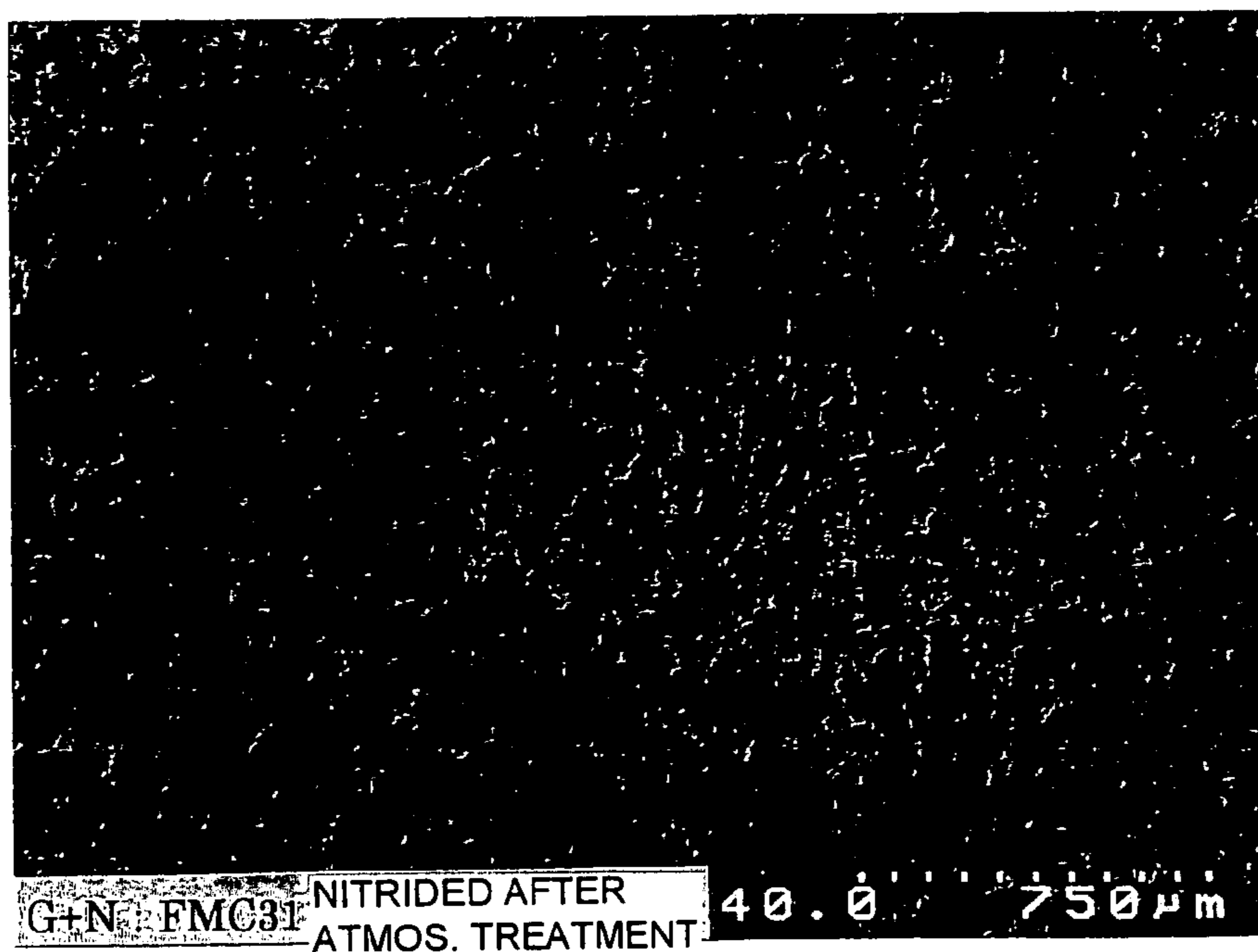
<p>SAMPLE X</p>	<p>VACUUM 1180°C x 1.0H SINTERING BATCH FURNACE ROOM TEMP GAS COOLING</p>	<p>CARBURIZING ATMOSPHERE 870°C x 1.0H OIL QUENCH QUENCHING CONTINUOUS FURNACE ROOM TEMP</p>	<p>ATMOSPHERE 480°C x 1.5H TEMPERING</p>
	<p>POWDER BONDING</p>	<p>MARTENSITIZING OF MATRIX</p>	<p>DECOMPOSITION OF REMAINING <math>\gamma</math>/RELAXATION OF QUENCHING DISTORTION</p>
<p>SAMPLE Y SAMPLE Z</p>	<p>VACUUM 1180°C x 1.0H SINTERING BATCH FURNACE ROOM TEMP GAS QUENCHING</p>	<p>NON-OXYGEN (NITROGEN) ATMOSPHERE</p>	<p>NON-OXYGEN (NITROGEN) ATMOSPHERE 580°C x 1.5H TEMPERING 580°C x 1.5H TEMPERING</p>
	<p>POWDER BONDING + MARTENSITIZING OF MATRIX</p>	<p>MARTENSITIZING OF MATRIX</p>	<p>DECOMPOSITION OF REMAINING <math>\gamma</math>/RELAXATION OF QUENCHING DISTORTION</p>
	<p>SINTERING</p>	<p>QUENCHING</p>	<p>TEMPERING</p>



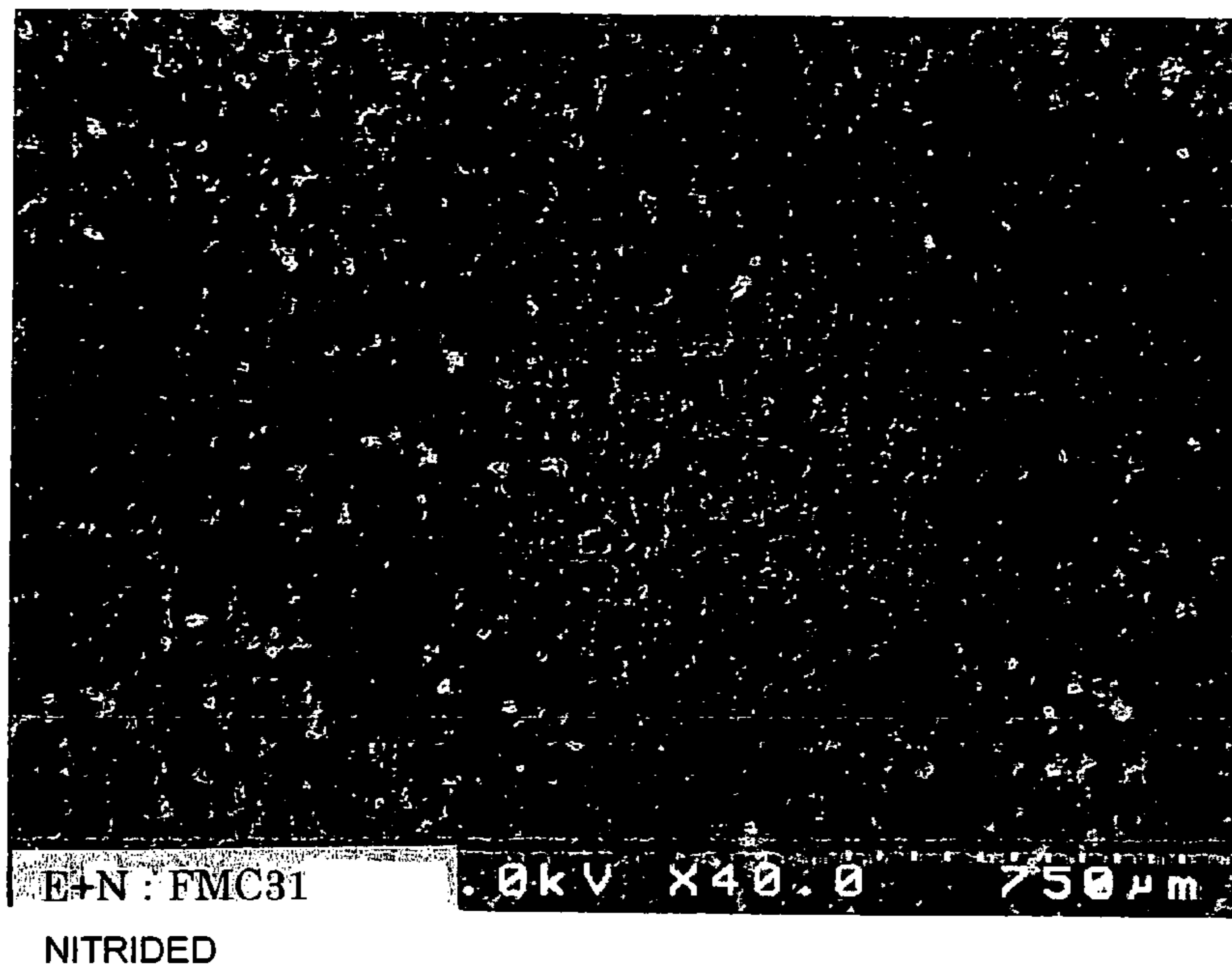
*Fig. 6*



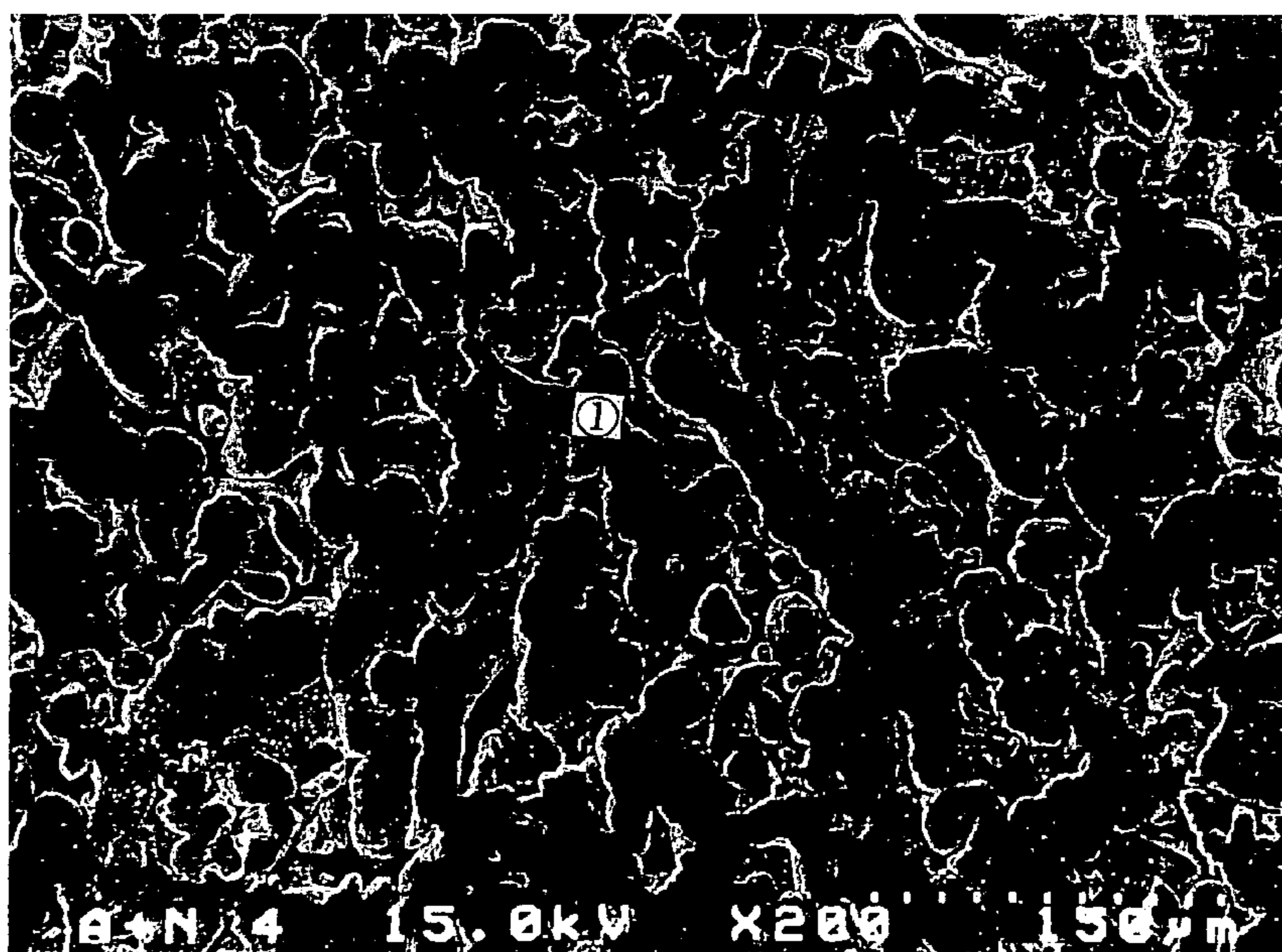
*Fig. 7*



*Fig. 8*

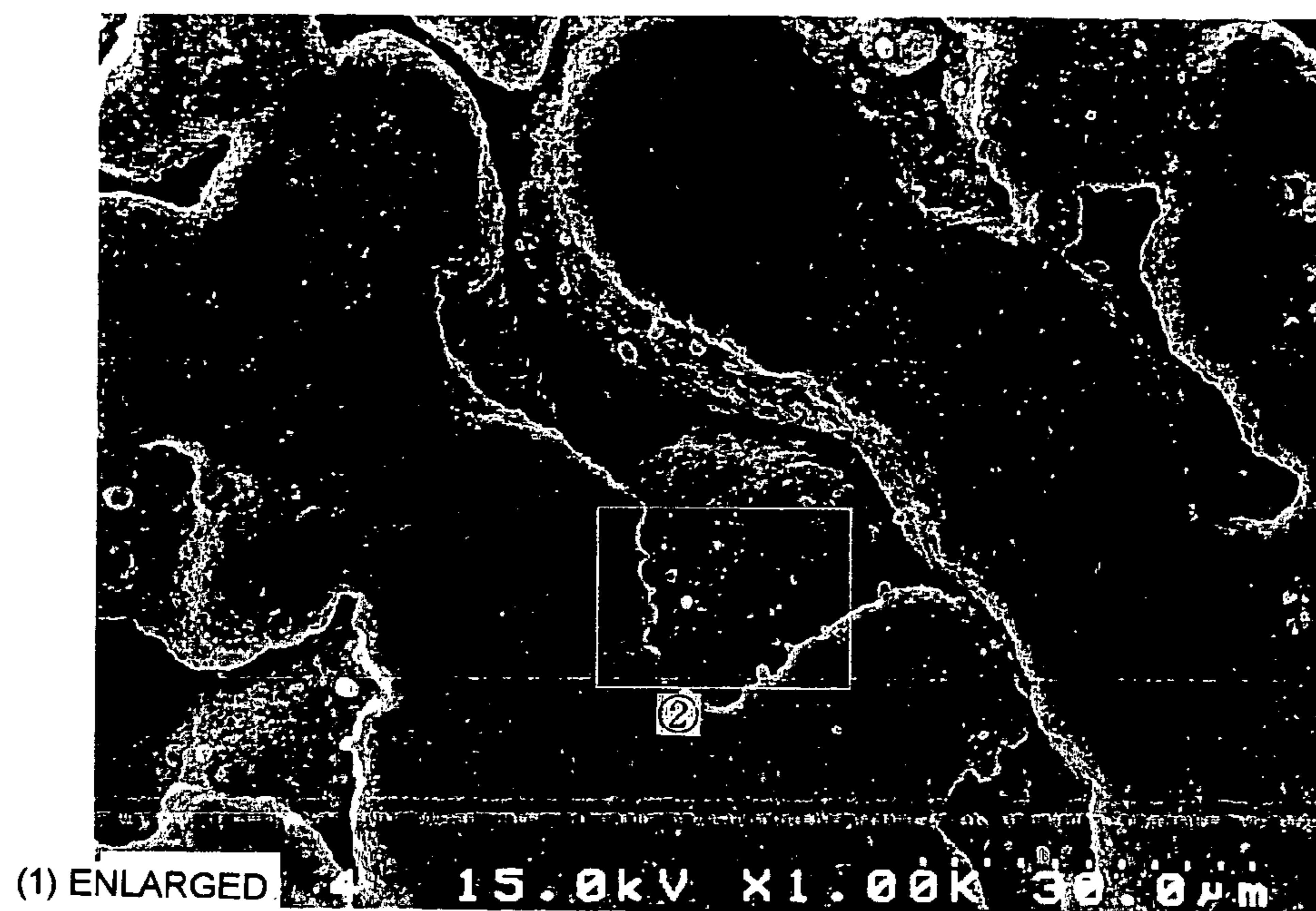


*Fig. 9*





*Fig. 10*

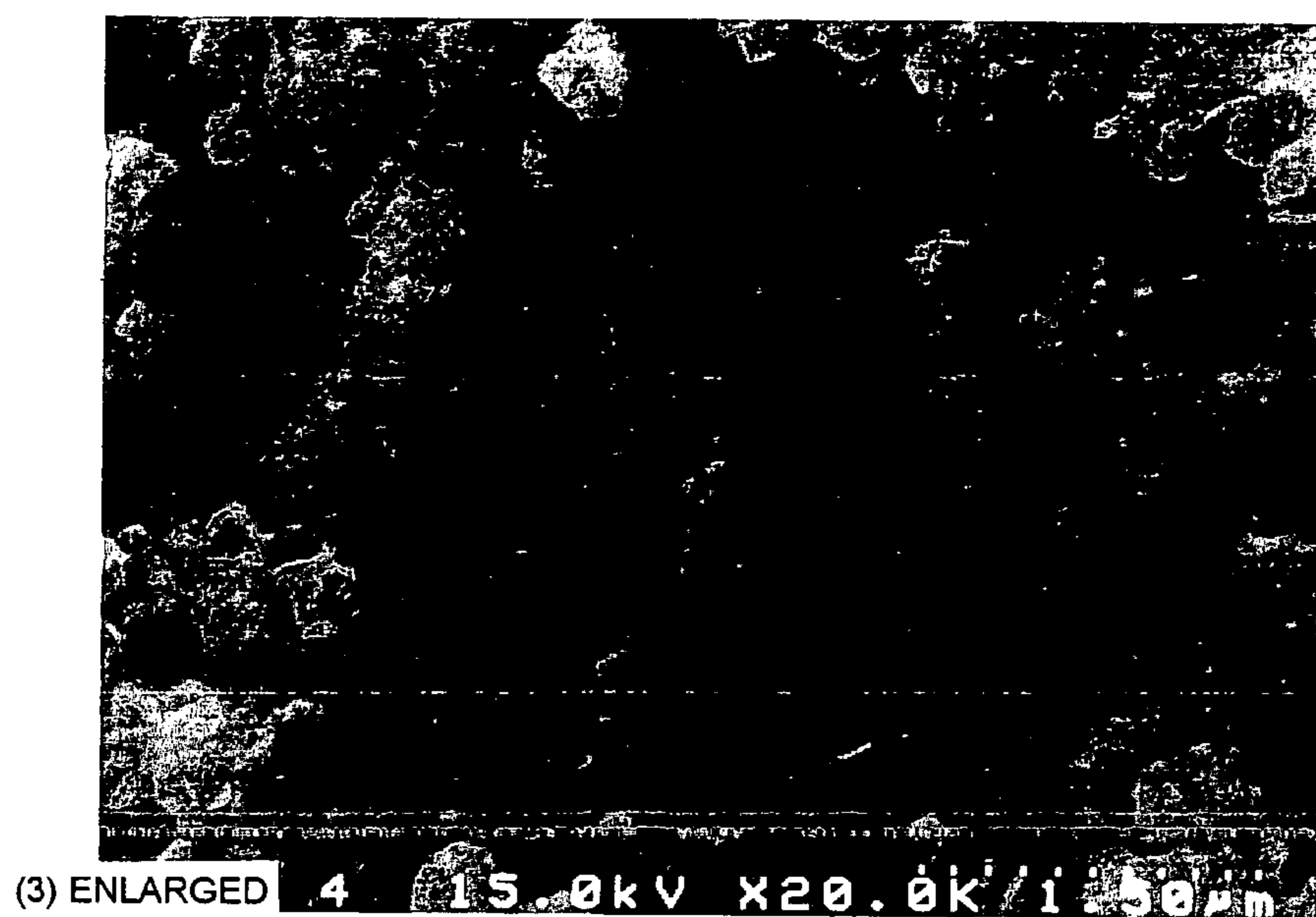


*Fig. 11*





*Fig. 12*



*Fig. 13*

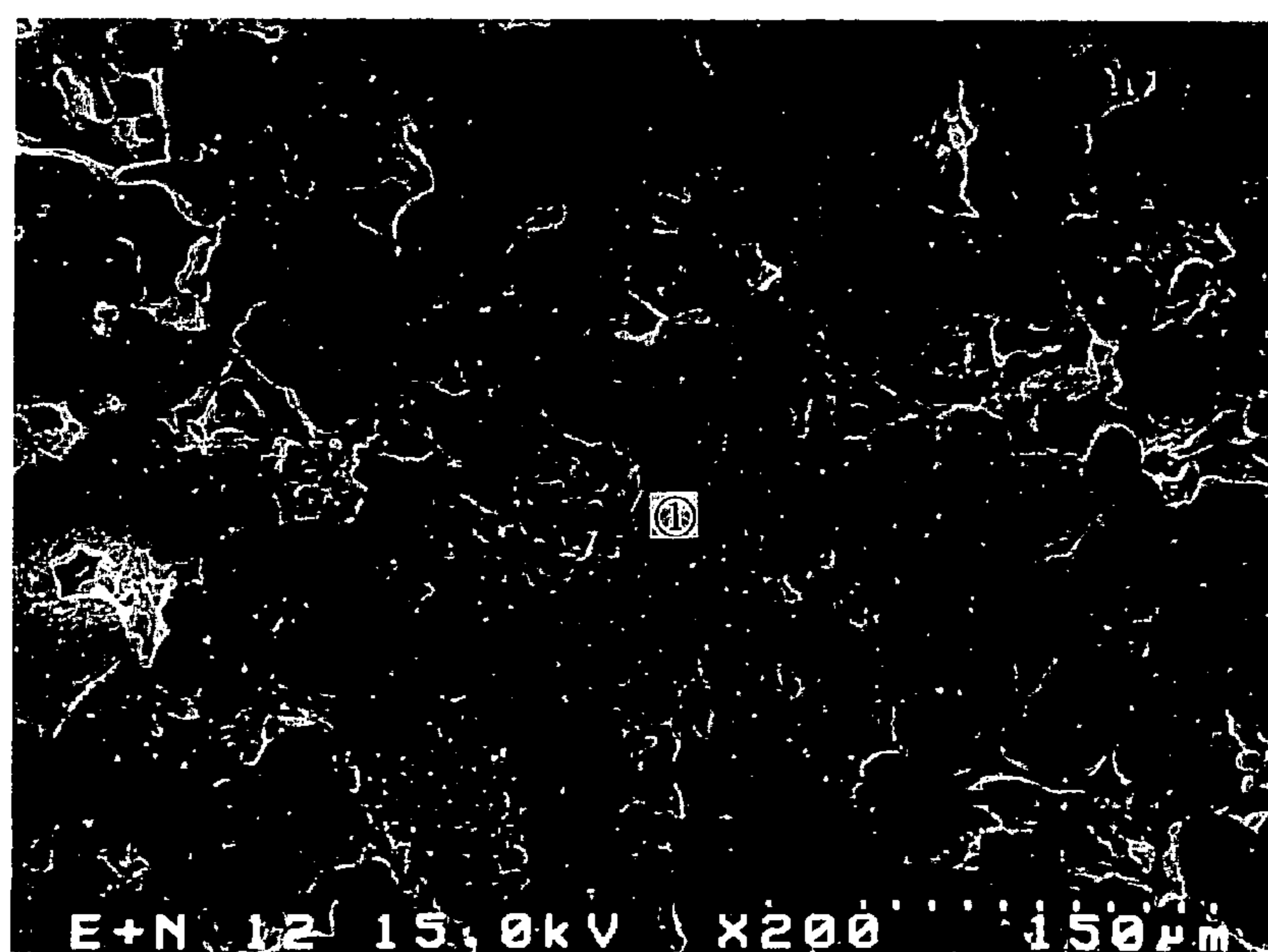


Fig. 14

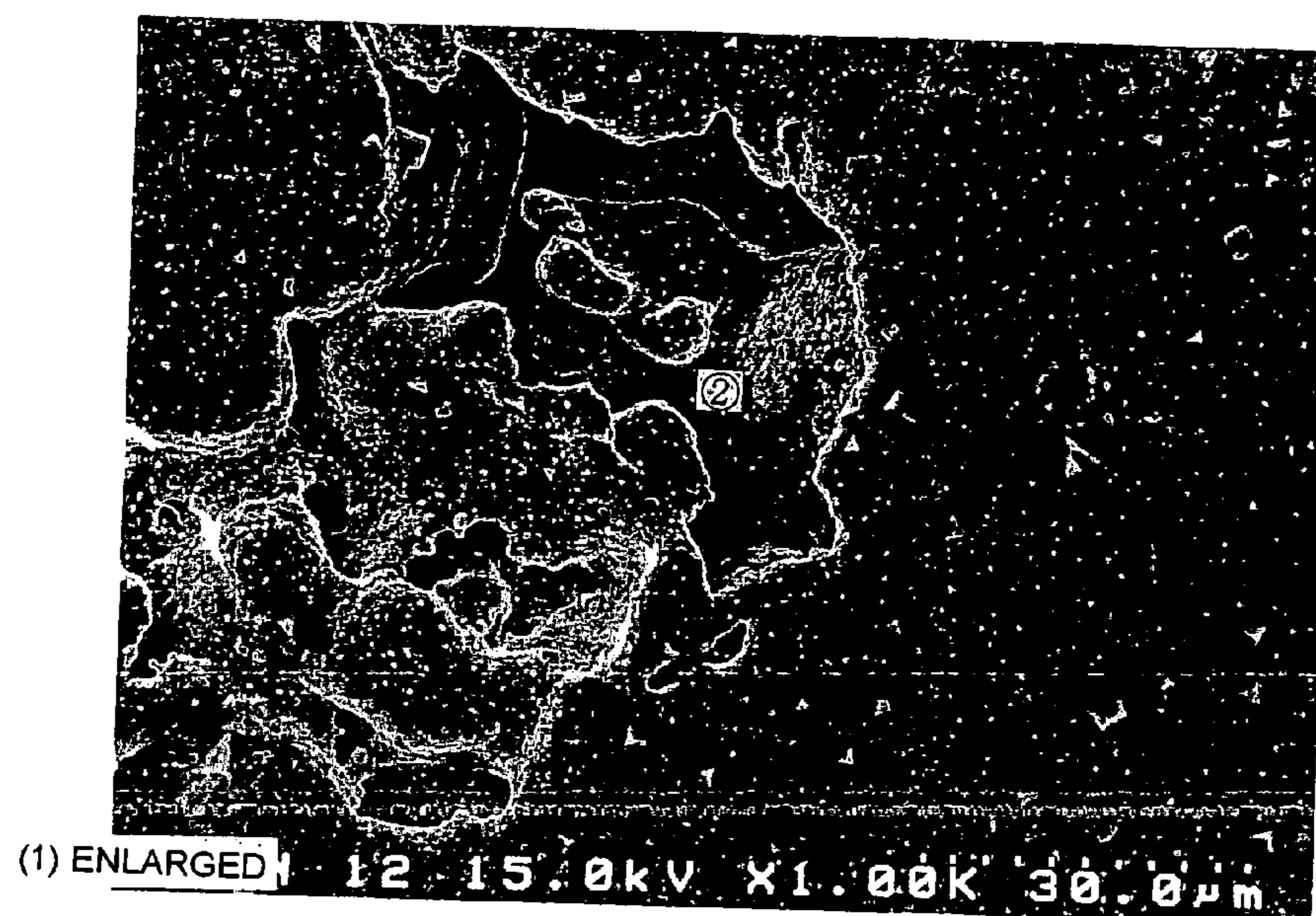


Fig. 15

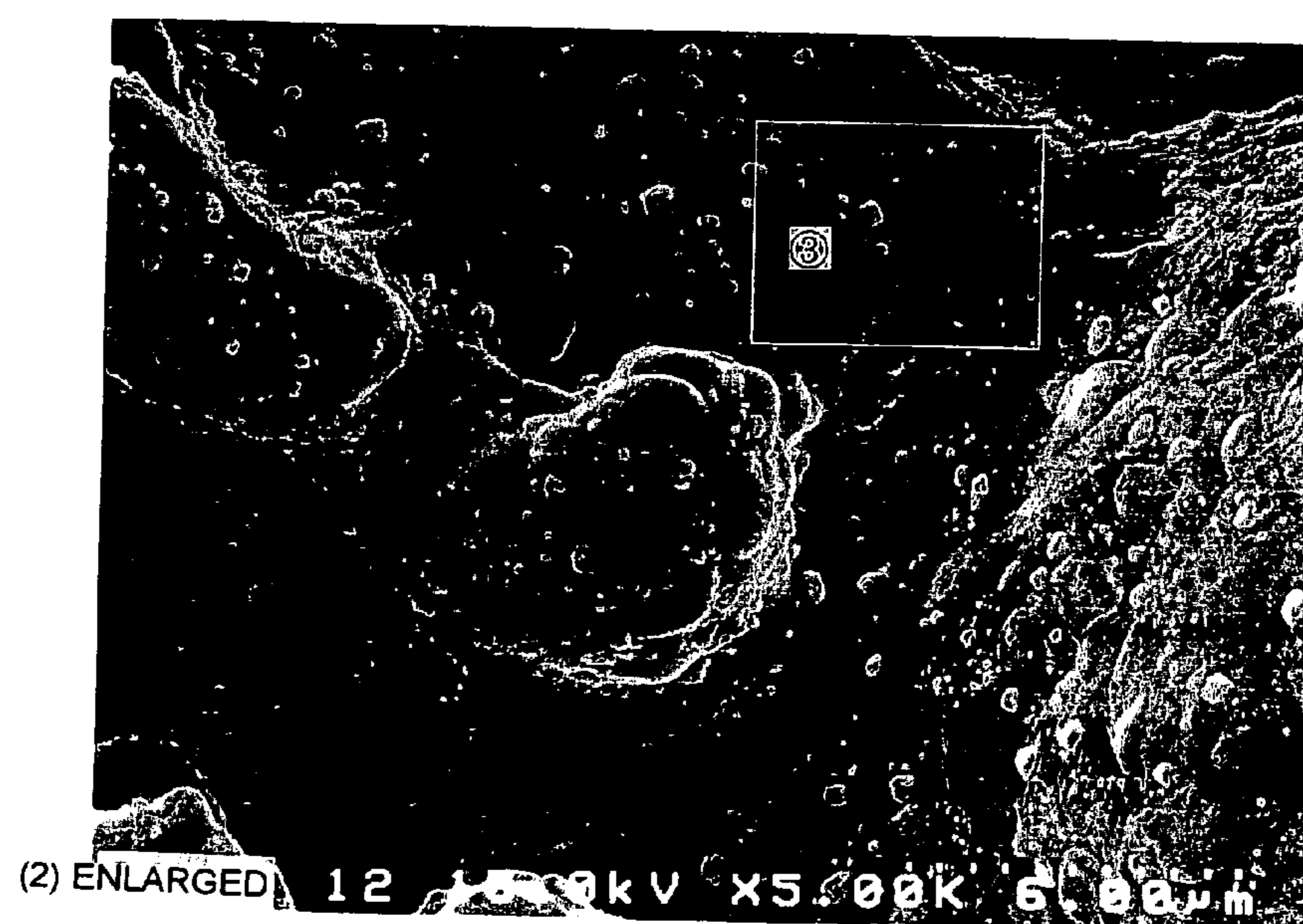




Fig. 16

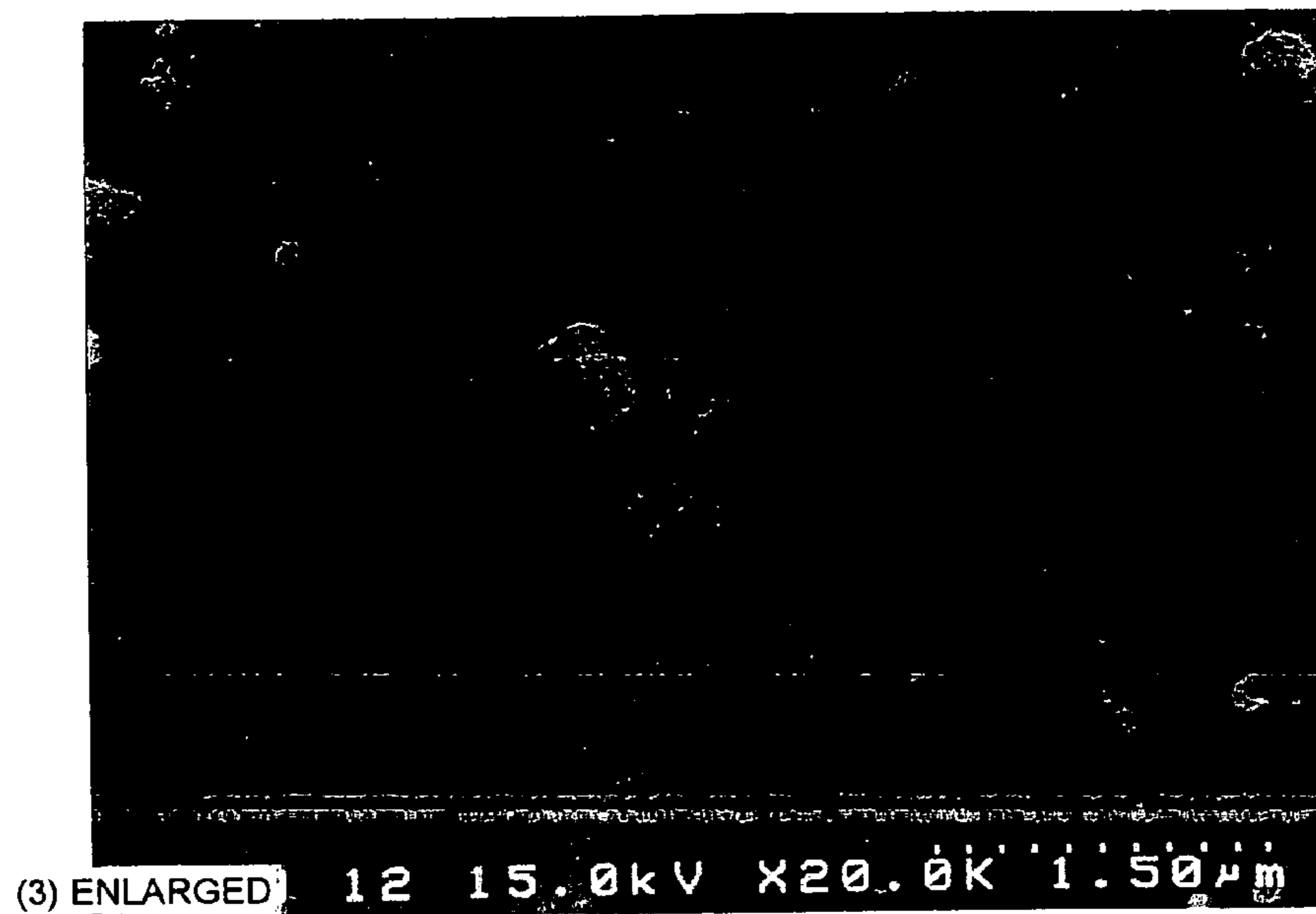
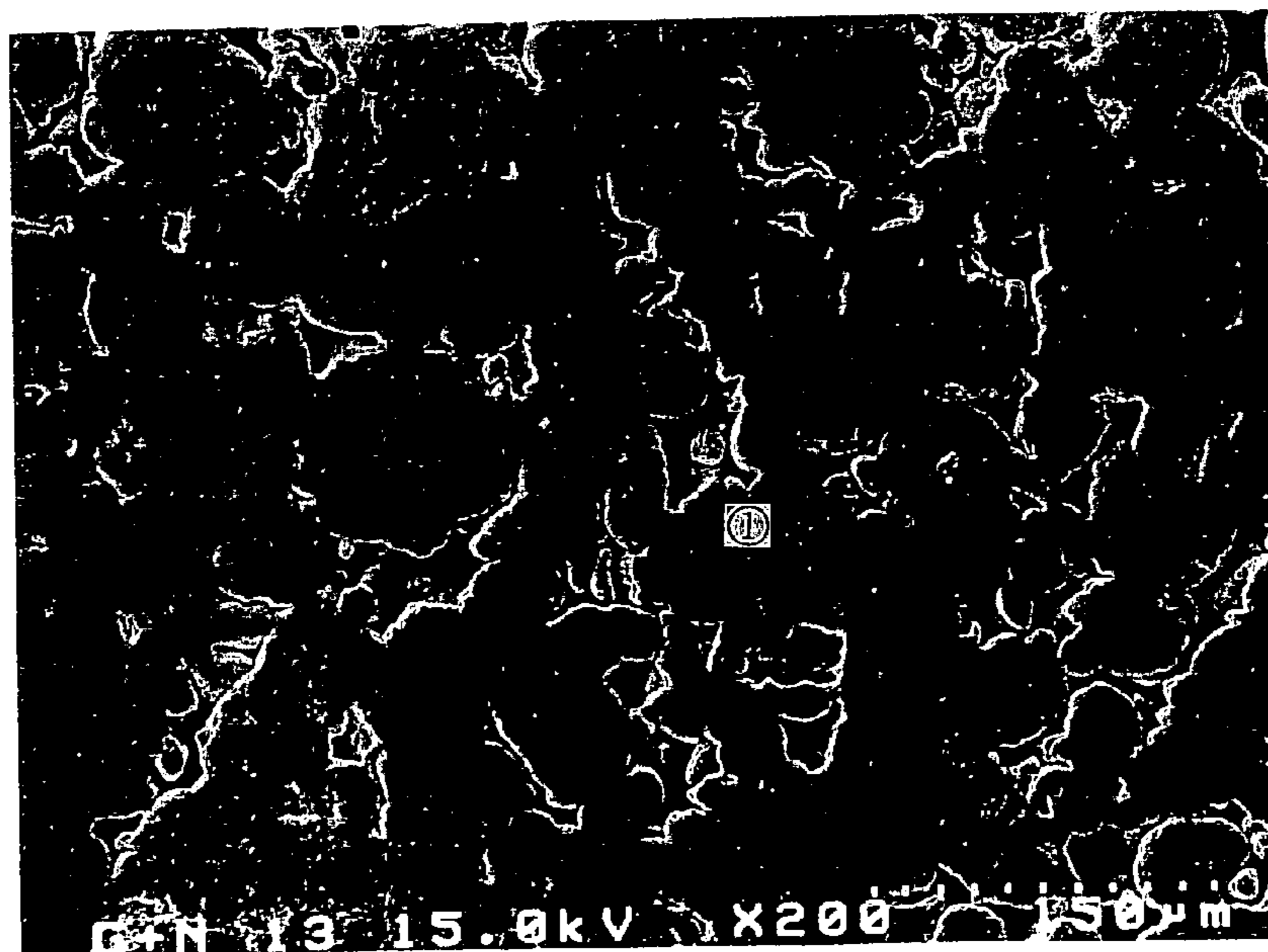
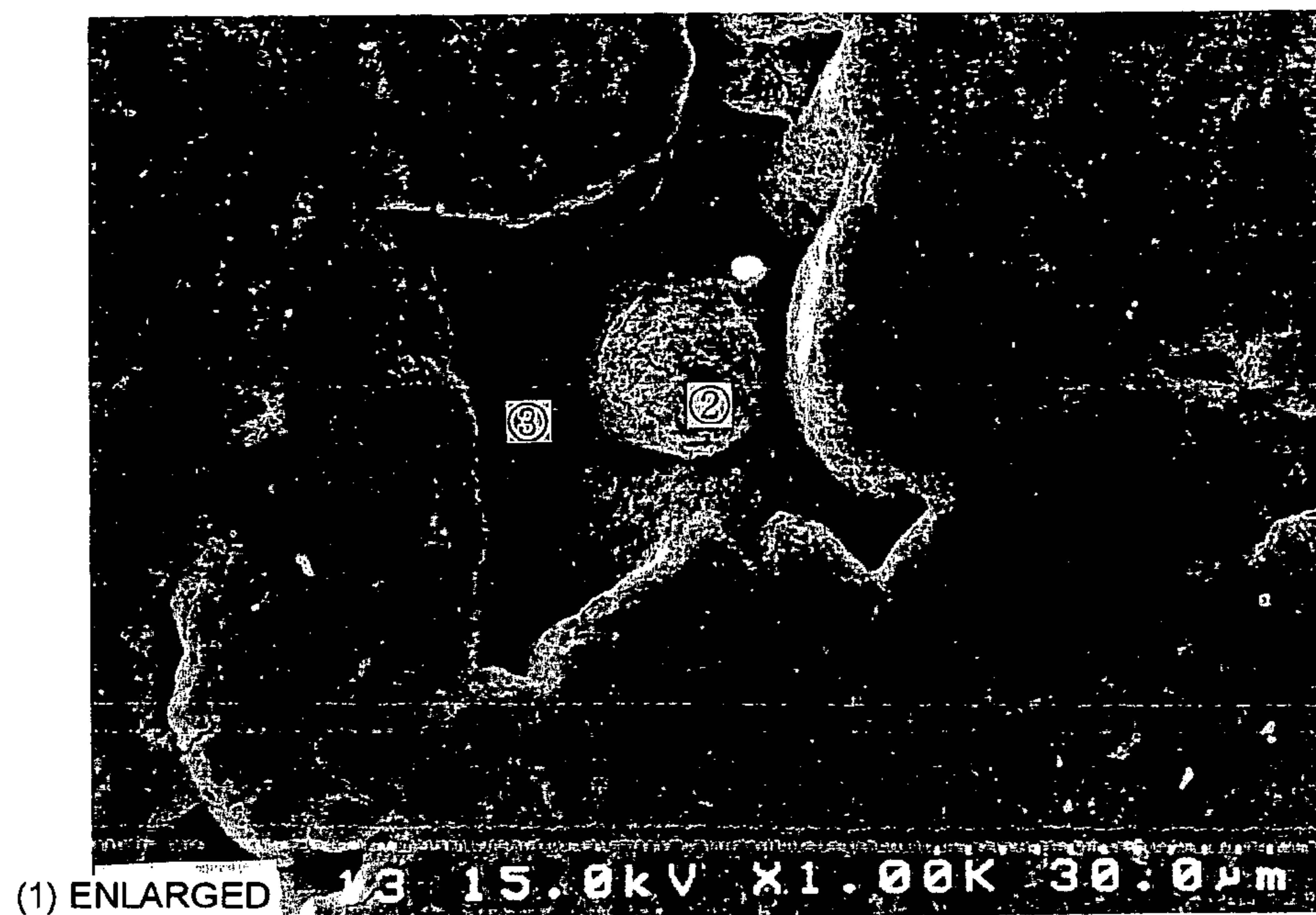


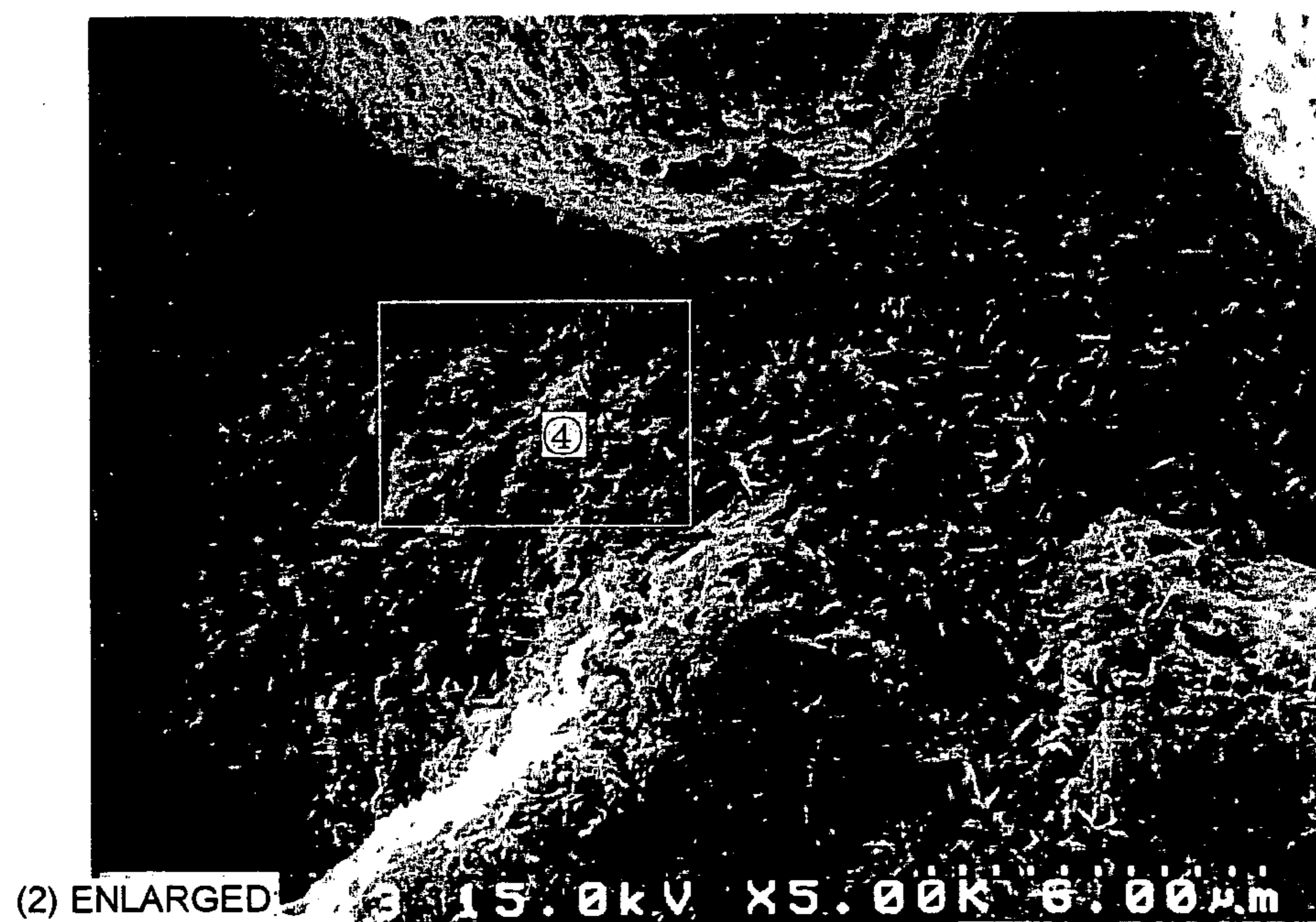
Fig. 17



*Fig. 18*

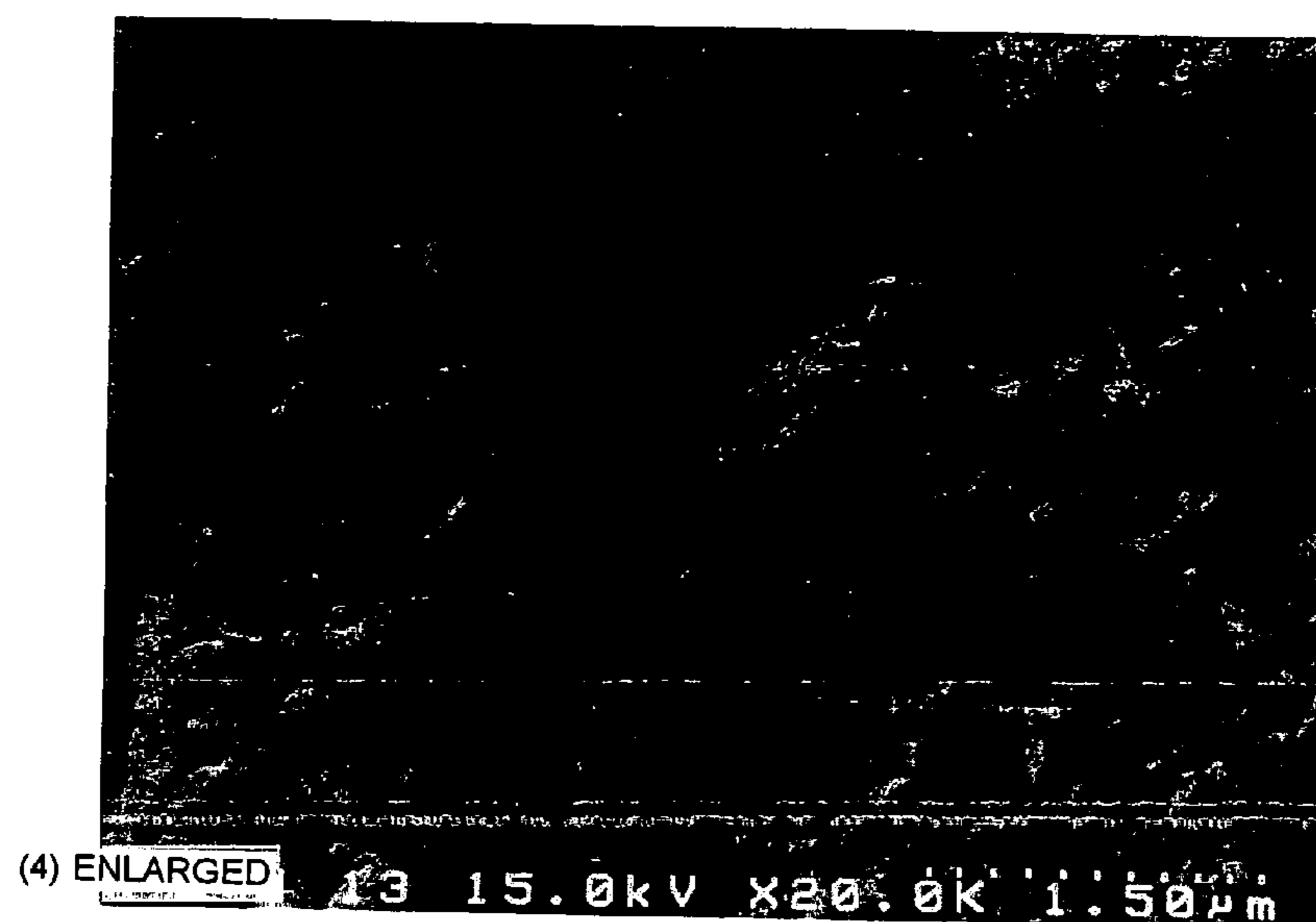


*Fig. 19*

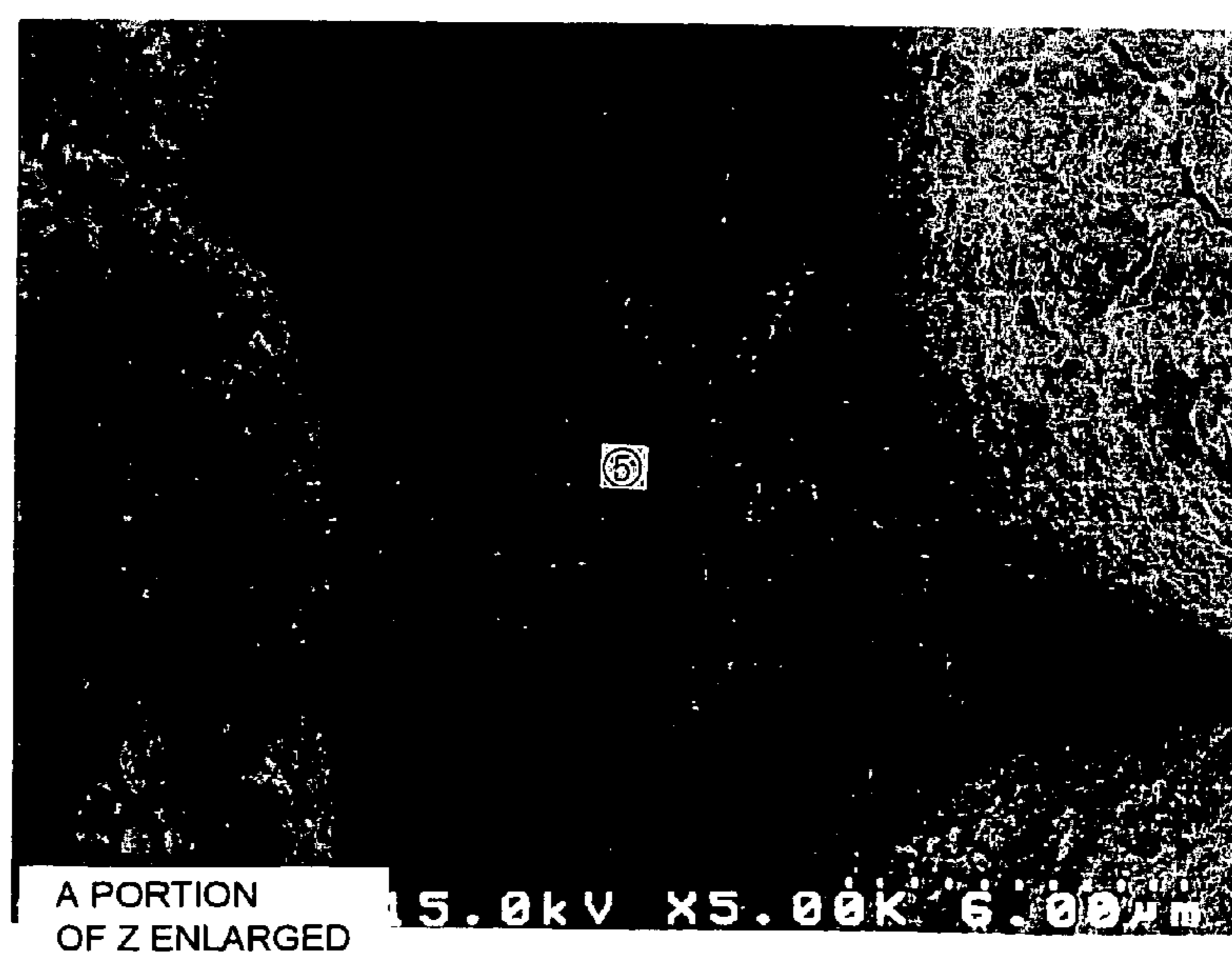




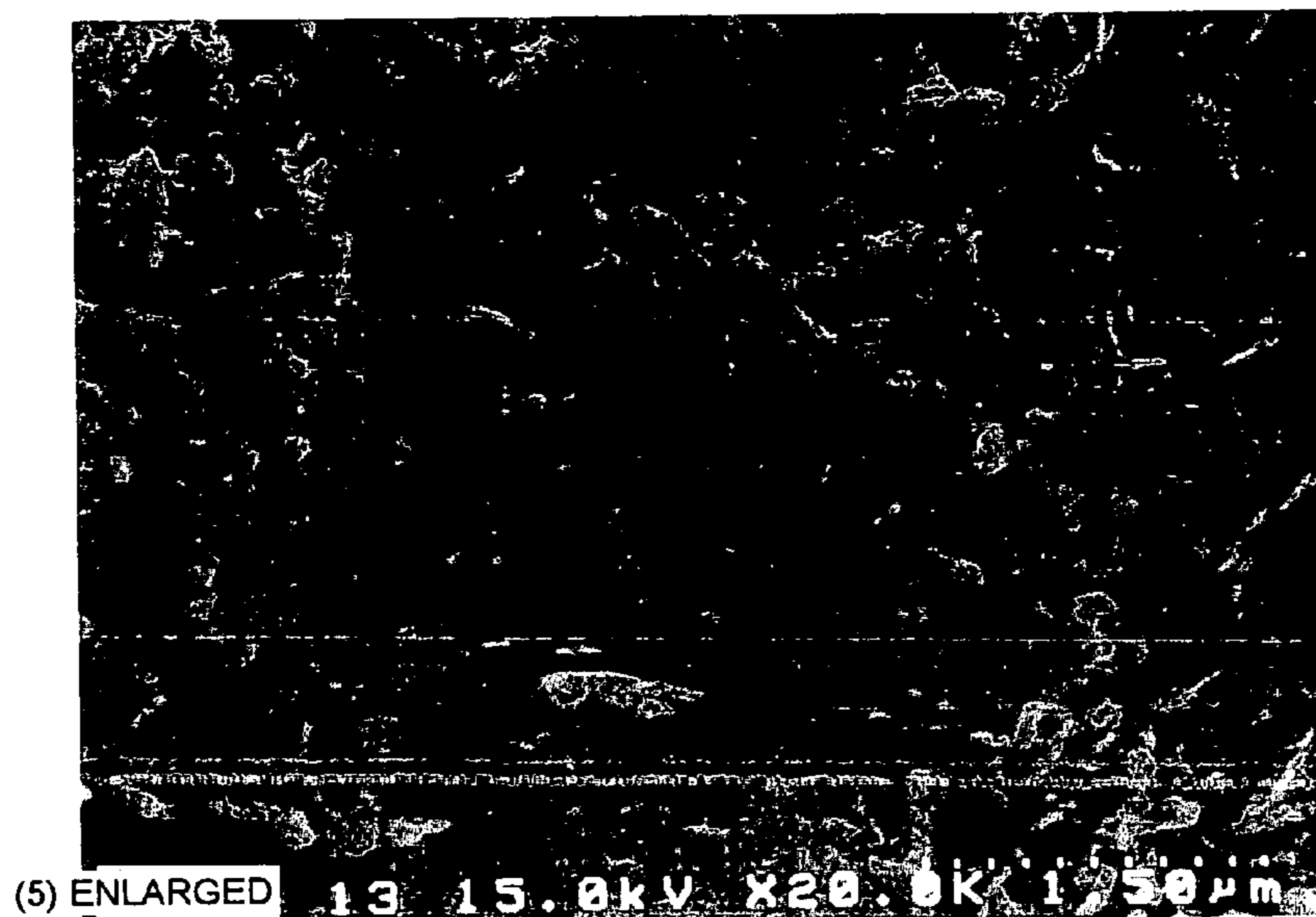
*Fig. 20*



*Fig. 21*

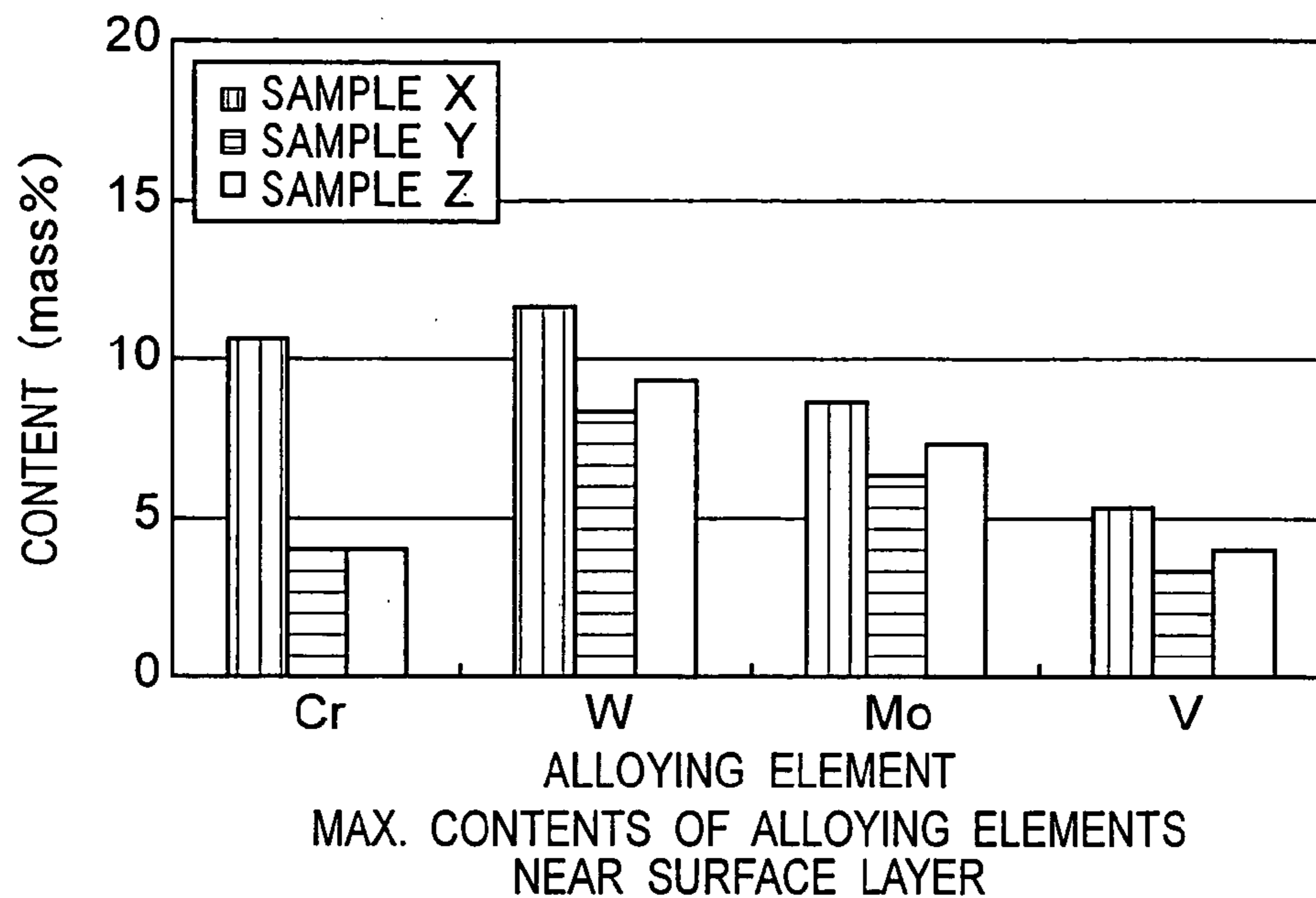


*Fig. 22*

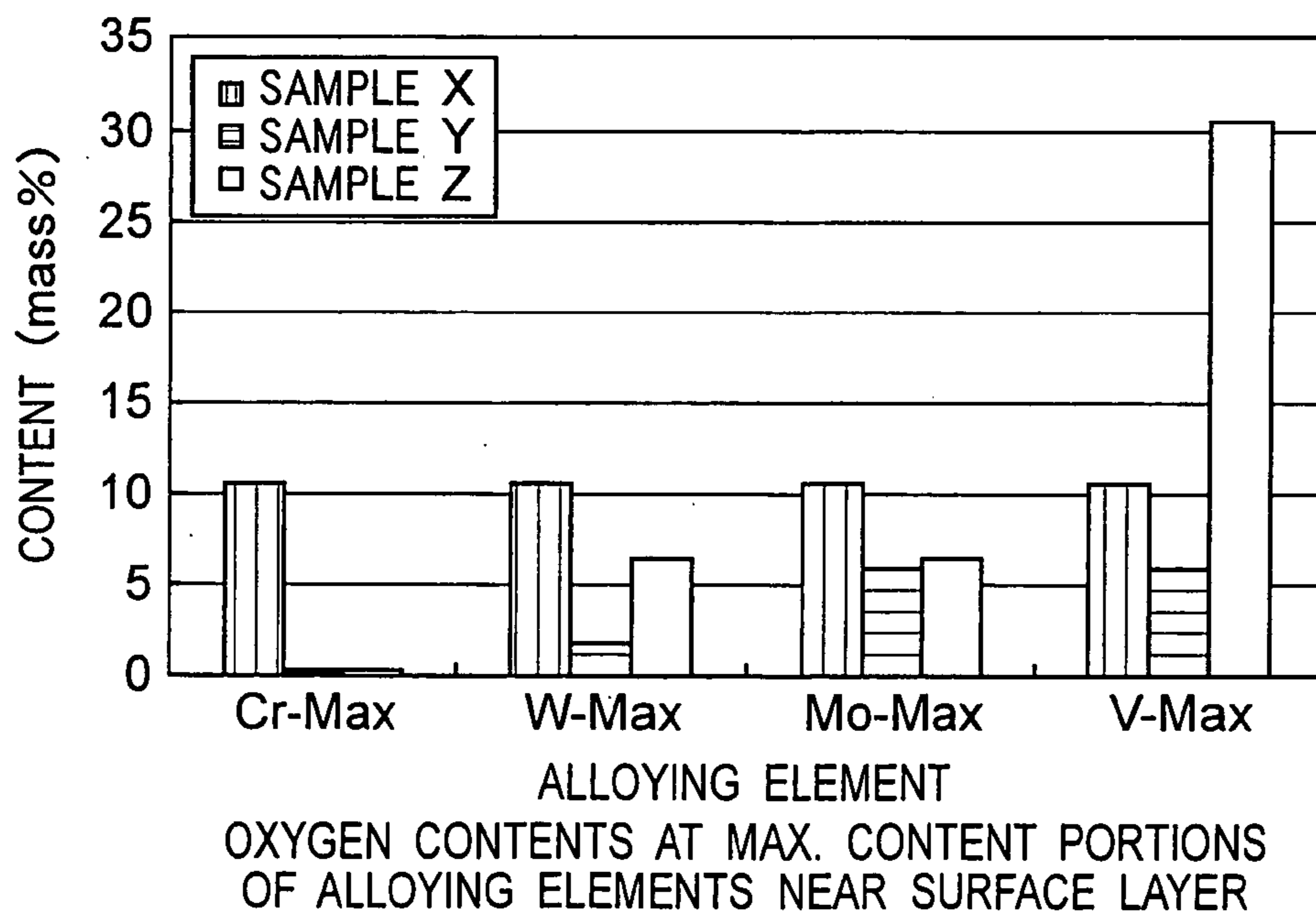




*Fig. 23*



*Fig. 24*



## WEAR-RESISTANT ELEMENTS AND METHOD OF MAKING SAME

### TECHNICAL FIELD

[0001] The present invention relates to wear-resistant elements having an increased hardness by nitriding and also to a method of making the same.

### BACKGROUND ART

[0002] A vane mounted in, for example, rotary compressors is slidably received within a vane groove defined in a cylinder. Because the vane is held in sliding contact at its side surfaces with side walls of the vane groove and at its end portion with a roller, the vane must have wear resistance. For this purpose, a material having a base material for which steel, a sintered metal or cast iron containing chromium is used and which is soft-nitrided has been proposed. This material has a first compound layer or surface layer of Fe—Cr—N and a second compound layer of the same composition formed below the first compound layer (see Document 1).

[0003] Another material has been proposed having a nitrided layer that is formed by nitriding the surface of a base material of stainless steel (see Document 2).

[0004] A further material has been proposed wherein an iron-based powdery material is used. This material is obtained by quenching and tempering sintered iron having a porosity or void volume below 10% or 15% to cause the matrix to have a martensitic structure, and subsequently nitriding or soft-nitriding the surface thereof to form an Fe—N compound layer therein and a nitrogen-diffused layer below it (see Document 3 or 4).

[0005] Document 1: Japanese Laid-Open Patent Publication No. 60-26195

[0006] Document 2: Japanese Laid-Open Patent Publication No. 11-101189

[0007] Document 3: Japanese Laid-Open Patent Publication No. 2001-140782

[0008] Document 4: Japanese Laid-Open Patent Publication No. 2001-342981

[0009] In the above-described materials, the surface is formed with an Fe—Cr—N or Fe—N compound layer or an Fe—Cr—N diffused layer and, hence, has a single composition and a uniform hardness. Accordingly, if a wear-resistant element such as a vane for use in a compressor is made of one of such materials, the vane tends to wear uniformly during operation of the compressor. As a result, the surface is hard to maintain desired oil retaining properties, and there is a possibility of seizing.

[0010] The present invention has been developed to overcome the above-described disadvantages.

[0011] It is accordingly an objective of the present invention to provide a highly reliable wear-resistant element having a surface of different hardness in which minute oil holes are formed to enhance the oil retaining properties during operation and to eliminate the deficiencies such as seizing.

### DISCLOSURE OF THE INVENTION

[0012] In accomplishing the above objective, a method of making a wear-resistant element according to the present invention is characterized by shaping and sintering a material into a compact using iron-based alloy powder containing Cr, and conducting a nitriding treatment having no carburizing action to the compact, thereby causing a surface of the compact to have a mixed structure of an Fe—Cr—N compound layer, an Fe—Cr—N diffused layer, and a matrix.

[0013] In another aspect of the present invention, a method of making a wear-resistant element is characterized by shaping and sintering a material into a compact using alloy powder in which at least one metallic element selected from Mn, Ti and V is contained in iron-based alloy powder containing Cr, and conducting a nitriding treatment having no carburizing action to the compact, thereby causing a surface of the compact to have a mixed structure of an Fe—Cr—N compound layer, an Fe—Cr—N diffused layer, and a matrix.

[0014] It is preferred that the compact has pores formed in the surface thereof, the Fe—Cr—N compound layer being formed at locations adjacent the pores, the mixed structure of the Fe—Cr—N diffused layer and the matrix being formed at locations remote from the pores.

[0015] In a further aspect of the present invention, a method of making a wear-resistant element is characterized by shaping and sintering a material into a compact using iron-based alloy powder containing Cr, and conducting a nitriding treatment having no carburizing action to the compact, thereby causing a surface of the compact to have a mixed structure of an Fe—Cr—N compound layer, an Fe—Cr—N diffused layer, and a matrix of a sorbite structure.

[0016] In this case, the compact preferably has pores formed in the surface thereof, the Fe—Cr—N compound layer being formed at locations adjacent the pores, the mixed structure of the Fe—Cr—N diffused layer and the matrix of the sorbite structure being formed at locations remote from the pores.

[0017] In a still further aspect of the present invention, a method of making a wear-resistant element is characterized by shaping and sintering a material into a compact using iron-based alloy powder containing Cr, quenching and tempering the compact, conducting a nitriding treatment having no carburizing action to the compact, and partially removing a surface of the compact, thereby causing the surface of the compact to have a mixed structure containing at least an Fe—Cr—N compound layer.

[0018] Before the nitriding treatment, an atmospheric treatment, i.e., a slight oxidation treatment may be conducted to the compact, and the preferred temperature of the atmospheric treatment is 380° C. or more.

[0019] A wear-resistant element includes a sintered and nitrided material having a mixed structure of an Fe—Cr—N compound layer, an Fe—Cr—N diffused layer, and a matrix formed in the surface thereof. It is preferred that the surface of the sintered and nitrided material be entirely covered with grains or protrusions of 0.1~0.5  $\mu\text{m}$ .

### EFFECTS OF THE INVENTION

[0020] The present invention has the above-described features and offers the following effects.



[0021] A material is first shaped and sintered into a compact using iron-based alloy powder containing Cr or using alloy powder in which at least one metallic element selected from Mn, Ti and V is contained in iron-based alloy powder containing Cr, and a nitriding treatment having no carburizing action is subsequently conducted to the compact, thereby causing a surface of the compact to have a mixed structure of a compound layer, a diffused layer, and a matrix. Accordingly, the amount of processing of the soft matrix portion increases during the finishing of the wear-resistant element to thereby form minute hollows, i.e., minute oil holes. When the wear-resistant element is in operation, slight wear occurs in the soft matrix portion to thereby form oil holes, making it possible to realize a highly reliable wear-resistant element free from seizing.

[0022] Furthermore, when the alloy powder in which at least one metallic element selected from Mn, Ti and V is contained in iron-based alloy powder containing Cr is used, the compound layer and the diffused layer come to contain at least one of Cr, Mn, Ti and V. Fe or Cr acts to ensure a desired hardness, Mn acts to further enhance the hardness, Ti acts to promote the nitriding treatment, and V acts to make the nitriding depth deep, making it possible to further enhance the reliability of the wear-resistant element.

[0023] Also, iron-based alloy powder containing Cr is first shaped and sintered into a compact, which is in turn quenched and tempered, and a nitriding treatment having no carburizing action is subsequently conducted to the compact, thereby causing a surface of the compact to have a mixed structure of a compound layer, a diffused layer, and a matrix of a sorbite structure. Accordingly, the amount of processing of the soft matrix portion increases during the finishing of the wear-resistant element to thereby form minute hollows, i.e., minute oil holes. When the wear-resistant element is in operation (relative frictional motion), slight wear occurs in the matrix portion that is softer than the compound layer and the diffused layer to thereby form oil holes. In addition, because the quenching and tempering increase the hardness of the matrix structure, a subsequent nitriding treatment further enhances the hardness of the compound layer and the diffused layer, making it possible to realize a seizing-free and highly reliable wear-resistant element having an increased wear resistance.

[0024] Alternatively, a material is first shaped and sintered into a compact, which is in turn quenched and tempered, a nitriding treatment having no carburizing action is subsequently conducted to the compact, and a surface of the compact is then partially removed, thereby causing the surface of the compact to have an Fe—Cr—N compound layer and also have variations in hardness. Accordingly, the amount of processing of the soft matrix portion increases during the finishing of the wear-resistant element to thereby form minute hollows, i.e., minute oil holes. When the wear-resistant element is in operation (relative frictional motion), slight wear occurs in the soft portions to thereby form oil holes. The oil holes act to enhance the lubricating properties, while the portion other than the oil holes, i.e., the portion of the compound layer acts to maintain the wear resistance, making it possible to enhance the reliability of the wear-resistant element.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0025] FIG. 1 is a photograph depicting a section of a wear-resistant element according to the present invention upon etching.

[0026] FIG. 2 is a photograph depicting a surface of the wear-resistant element of FIG. 1 upon grinding and etching.

[0027] FIG. 3 is a photograph depicting impressions formed on another surface of the wear-resistant element of FIG. 1 when Micro Vickers hardness measurements have been conducted.

[0028] FIG. 4 is a graph depicting hardness distribution curves of the wear-resistant element of FIG. 1.

[0029] FIG. 5 is a diagram depicting heat treatment patterns conducted to materials of samples.

[0030] FIG. 6 is a photograph depicting a surface condition of sample X at  $\times 40$  magnification after nitriding.

[0031] FIG. 7 is a photograph depicting a surface condition of sample Y at  $\times 40$  magnification after nitriding.

[0032] FIG. 8 is a photograph depicting a surface condition of sample Z at  $\times 40$  magnification after nitriding.

[0033] FIG. 9 is a photograph depicting a surface condition of sample X at  $\times 200$  magnification after nitriding.

[0034] FIG. 10 is a photograph depicting a surface condition of sample X at  $\times 1000$  magnification after nitriding.

[0035] FIG. 11 is a photograph depicting a surface condition of sample X at  $\times 5000$  magnification after nitriding.

[0036] FIG. 12 is a photograph depicting a surface condition of sample X at  $\times 20000$  magnification after nitriding.

[0037] FIG. 13 is a photograph depicting a surface condition of sample Y at  $\times 200$  magnification after nitriding.

[0038] FIG. 14 is a photograph depicting a surface condition of sample Y at  $\times 1000$  magnification after nitriding.

[0039] FIG. 15 is a photograph depicting a surface condition of sample Y at  $\times 5000$  magnification after nitriding.

[0040] FIG. 16 is a photograph depicting a surface condition of sample Y at  $\times 20000$  magnification after nitriding.

[0041] FIG. 17 is a photograph depicting a surface condition of sample Z at  $\times 200$  magnification after nitriding.

[0042] FIG. 18 is a photograph depicting a surface condition of sample Z at  $\times 1000$  magnification after nitriding.

[0043] FIG. 19 is a photograph depicting a surface condition of sample Z at  $\times 5000$  magnification after nitriding.

[0044] FIG. 20 is a photograph depicting a surface condition of sample Z at  $\times 20000$  magnification after nitriding.

[0045] FIG. 21 is a photograph depicting a surface condition of another portion of sample Z at  $\times 5000$  magnification after nitriding.

[0046] FIG. 22 is a photograph depicting a surface condition of another portion of sample Z at  $\times 20000$  magnification after nitriding.

[0047] FIG. 23 is a graph depicting maximum contents of alloying elements at a location adjacent a surface layer of each sample.



[0048] FIG. 24 is a graph depicting oxygen contents at the maximum content portions of the alloying elements at the location adjacent the surface layer of each sample.

#### EXPLANATION OF REFERENCE NUMERALS

- [0049] 1 pore
- [0050] 2 compound layer
- [0051] 3 mixed structure
- [0052] 8 Micro Vickers impression between pores

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0053] An embodiment of the present invention is explained hereinafter with reference to the drawings.

[0054] A wear-resistant element according to the present invention is used for a vane or the like that is mounted in, for example, a rolling piston. The wear-resistant element is obtained by vacuum sintering iron-based alloy powder containing Cr, such as powdery HSS (powdery high-speed steel), at a temperature of about 1200° C. to mold it into a desired shape, conducting a quenching treatment to turn it into a martensitic structure, conducting a tempering treatment at a temperature of 480° C.~580° C. to turn it into a sorbite structure, and conducting a gas nitriding treatment having no carburizing action for about six hours at a temperature of 400° C. below the tempering temperature.

[0055] FIG. 1 depicts a section structure of the wear-resistant element according to the present invention obtained in the above-described manner. The wear-resistant element shown therein has been etched after the gas nitriding treatment, making it possible to easily observe a compound layer.

[0056] Because the material has been made by sintering and molding a green compact, the density thereof increases up to only about 80~90%, and many pores or voids 1 exist therein. Furthermore, a gas used for the nitriding treatment has passed through the pores 1 to thereby nitride inner parts of the material, and a white compound layer 2 has been formed around the pores 1. As the distance from the pores 1 increases, the number of black portions 3 increases. The black portions 3 have a mixed structure of a diffused layer and a matrix.

[0057] FIG. 2 depicts a surface of the wear-resistant element at  $\times 450$  magnification when it has been cut in a direction perpendicular to the surface of FIG. 1 (that is, it has been cut at a predetermined depth from the surface), and the cut surface has been ground.

[0058] As shown in FIG. 2, the pores 1 peculiar to the sintered and molded green compacts exist in the machined surface, and because the nitriding gas entering the pores 1 has progressed the nitriding around the pores 1, an Fe—Cr—N compound layer 2 around the pores 1 has become white upon etching. The white portion decreases at locations remote from the surfaces of the pores 1, and a mixed structure 3 of an Fe—Cr—N diffused layer and the matrix exist there. That is, the surface of the wear-resistant element having the pores 1 therein has the mixed structure 3 of the compound layer 2, the diffused layer, and the matrix structure.

[0059] FIG. 3 is a photograph of impressions formed on a section of the wear-resistant element when Micro Vickers hardness measurements have been conducted. The smaller the impressions are, the harder the Micro Vickers hardness is. As is clear from the size of the Micro Vickers impressions, the portions around the pores 1 have small impressions, while the size of the Micro Vickers impressions between the pore 1 and the pore 1 is large compared with the portions around the pores 1, indicating a reduction in hardness. It is conceivable that because the compound layer 2 has been created around the pores 1 by the nitriding gas entering such portions, and the portions 8 between the pore 1 and the pore 1 have turned into the mixed structure 3 of the diffused layer and the matrix, the portions 8 have a hardness lower than that of the portions around the pores 1.

[0060] Because the surface hardness varies moderately, the amount of processing of the soft matrix portion increases during the finishing of the wear-resistant element, thus forming minute hollows, i.e., minute oil holes. When the wear-resistant element is in operation, the portions having the soft matrix structure are slightly worn away and serve as the oil holes. Accordingly, in addition to the pores in the sintered and molded green compact, the oil holes having a high wedge effect are created over the entire surface of a movable element or an element confronting it. As a result, the surface comes to have increased oil retaining properties and improved lubricating properties as a whole, while the compound layer and the diffused layer around the pores can ensure the wear resistance, making it possible to ensure a desired reliability, compared with the wear-resistant elements that are hard throughout the entire surface thereof.

[0061] It is to be noted here that although the above-described embodiment has been explained taking the case of a quenched and tempered article of powdery HSS, the material may be made of generally available alloy powder. Similar effects can be obtained using alloy powder in which at least one metallic element selected from Mn, Ti and V is contained in iron-based alloy powder containing Cr.

[0062] FIG. 4 depicts hardness distribution curves of the wear-resistant element of FIG. 1 after the nitriding treatment. As shown therein, the hardness at position A of a depth of more than 0.4 mm from the surface is still almost the same as the hardness at surface B. The surface structure is, when the surface of this wear-resistant element has been machined or ground by about 0.1 mm and subsequently etched at position C of a depth of 0.1 mm from the surface, shown in FIG. 2.

[0063] In the case of the sintered green compact of powdery HSS, even a short-time nitriding treatment can allow the nitriding gas to easily enter the inner parts of the material because of the presence of the pores therein, resulting in deep nitriding. Whereas the normal nitriding treatment requires a nitriding treatment after a rough machining of the material and a subsequent finish machining, the sintered green compact of powdery HSS can easily obtain a desired hardness by a nitriding treatment of the material and a subsequent finish machining. Even if the machining allowance becomes ununiform due to deformation caused by the quenching and tempering of the material, the deep nitriding can minimize the variations in the surface hardness of the compound layer that is the highest one in a finished product. Although the surface removal exposes the mixed structure of



the Fe—Cr—N diffused layer and the matrix as well as the Fe—Cr—N compound layer, this can be readily understood from the fact that low hardness portions exist at locations close to the surface. Because the wear-resistant element according to the present invention can dispense with the rough machining, it can be manufactured at a low cost while maintaining a superior wear resistance.

#### EXAMPLE 1

[0064] Three kinds of iron-based alloy powder were formed into a predetermined shape, and each compact so shaped was vacuum-sintered at a predetermined temperature (for example, 1180° C.) to thereby form a sintered compact, which was in turn heat-treated in a predetermined fashion, and thereafter, the surface of each compact was inspected. The materials of the samples (sintered compacts) correspond to SKH51, and the samples are hereinafter referred to as samples X, Y and Z.

[0065] Table 1 indicates results of a component analysis of samples X, Y and Z after the heat treatment.

TABLE 1

Material	W	Mo	Cr	V	Si	C	unit: wt % Others (Fe etc.)
Sample X	5.5~ 6.7	4.0~ 6.0	3.5~ 5.0	1.4~ 2.4	0.4~ 0.9	1.2~ 1.8	≤1.0
Sample Y	5.5~ 6.7	4.0~ 6.0	3.5~ 5.0	1.4~ 2.4	0.4~ 0.9	0.9~ 1.4	≤1.0
Sample Z	5.5~ 6.7	4.0~ 6.0	3.5~ 5.0	1.4~ 2.4	0.4~ 0.9	0.9~ 1.4	≤1.0

[0066] FIG. 5 depicts heat treatment patterns conducted to the materials of the samples. Table 2 indicates the material characteristics of the samples.

TABLE 2

Material	Density (g/cm <sup>3</sup> )	Hardness (HRA)	Transverse Rupture Strength (MPa)
Sample X	6.65~6.75	63.0~66.0 (Average 64.3)	544.9~765.9 (Average 617.6)
Sample Y	6.71~6.75	63.6~68.1 (Average 65.0)	743.6~902.7 (Average 774.4)
Sample Z	6.71~6.75	63.6~68.1 (Average 65.0)	743.6~902.7 (Average 774.4)

[0067] A six-hour nitriding treatment was conducted at a temperature of 400° C. with respect to samples X and Y, while a three-hour atmospheric treatment (slight oxidation treatment) was first conducted at a temperature of 480° C. and a six-hour nitriding treatment was subsequently conducted at a temperature of 400° C. with respect to sample Z.

[0068] The surface configuration and surface nature of each sample were then inspected and evaluated using a scanning electron microscope having magnifying powers of 40 to 20000.

[0069] FIGS. 6 to 8 depict surface conditions of samples X, Y and Z at ×40 magnification after the nitriding treatment. These figures reveal that samples Y and Z present similar surface conditions, while sample X presents minute granular configurations indicating active surface conditions, compared with samples Y and Z.

[0070] FIGS. 9 to 12 depict surface conditions of sample X at ×200, ×1000, ×5000 and ×20000 magnifications, respectively, while FIGS. 13 to 16 depict the surface conditions of sample Y at ×200, ×1000, ×5000 and ×20000 magnifications, respectively. FIGS. 17 to 20 depict the surface conditions of sample Z at ×200, ×1000, ×5000 and ×20000 magnifications, respectively, while FIGS. 21 and 22 depict surface conditions of another portion of sample Z at ×5000 and ×20000 magnifications, respectively.

[0071] FIGS. 9 to 12 reveal that there are small grains or particles bonded and sintered under pressure on the surface of sample X, innumerable minute protruding deposits exist on surfaces between the sintered grains, and deposition of nitride grains occurred around such minute deposits. That is, it can be understood that sample X was nitrided to the inner parts by the six-hour nitriding treatment at a temperature of 400° C.

[0072] FIGS. 13 to 16 reveal that sample Y has sintered grains larger than those of sample X. As can be seen by a comparison between FIGS. 9 and 10 and FIGS. 13 and 14, sample Y presents a relatively planar surface condition. The inspections at more than ×5000 magnifications also reveal that sample Y has a lesser number of minute protruding deposits than sample X, indicating unstable (inactive) surface conditions.

[0073] FIG. 17 (×200 magnification) reveals that sintered grains on the surface of sample Z are analogous to those on the surface of sample Y and are larger than those on the surface of sample X. However, the inspections at more than ×1000 magnifications as shown in FIGS. 18 to 22 reveal that sample Z has a more number of minute deposits than sample X on the surface thereof and between the sintered grains and, hence, sample Z microscopically presents surface conditions analogous to those of sample X.

[0074] A difference between sample Y and sample Z resides in whether or not the material underwent the atmospheric treatment after the sintering. The former was in an untreated condition, while the latter underwent the atmospheric treatment. The untreated material presents the planar and stable surface conditions as explained hereinabove, while sample Z treated in the atmosphere has innumerable protruding deposits on the surface thereof, which is hence active, like sample X.

[0075] On the other hand, the hardness of each sample after the nitriding is such as shown in Table 3.

TABLE 3

Distance from Surface (mm)	Sample X	Sample Y	Sample Z
0.01	1163 Hv	837 Hv	1240 Hv
0.50	1115 Hv	767 Hv	1175 Hv
1.00	1111 Hv	792 Hv	1087 Hv
1.50	1112 Hv	744 Hv	1080 Hv

[0076] As can be seen from Table 3, the hardness of sample Z at depths of 0.01 mm and 0.05 mm from the surface is the highest with that of sample X and that of sample Y following in this order.

[0077] Comparing the hardness shown in Table 3 and the aforementioned surface configurations, the deposited minute



grains on the surface of sample Z after the nitriding have the highest density, followed by that of sample Y and then followed by that of sample X, as shown in FIGS. 9 to 22. Because sample Z has minute oxide grains that were formed on the surface thereof by treating it in the atmosphere before the nitriding treatment, it is conceivable that a nitriding reaction in sample Z was facilitated by activating the surface thereof with the minute oxide grains deposited thereon.

[0078] In the case of sample Y, the hardness at a depth of 0.5 mm from the surface sometimes increased up to more than 900 Hv by increasing the nitriding temperature (for example, about 430° C.) or by lengthening the nitriding period of time (for example, about 10 hours) even when the nitriding temperature was 400° C., but the nitriding was unstable and cracks sometimes occurred.

[0079] Sample Z was treated in the atmosphere at varying temperatures of 280° C., 380° C., 480° C. and 580° C. while maintaining the treating period of time constant (three hours). The treatment at a temperature of 280° C. decreased the hardness below 900 Hv at a depth of 1.5 mm from the surface, but the treatments at temperatures of more than 380° C. increased the hardness over 900 Hv throughout a range from the surface to a depth of 1.5 mm.

[0080] That is, samples Y and Z are poor in nitriding capability, but a three-hour atmospheric treatment at a temperature of 380° C. and a subsequent six-hour nitriding treatment at a temperature of 400° C. enhanced the nitriding capability up to the level of sample X.

[0081] It is recognized that there are differences in the alloying elements (Cr, W, Mo, V) in proximity to the surface layer and in the oxygen content among the samples, and the difference in the element content distribution has influence on the nitriding reaction.

[0082] More specifically, upon inspection of the surface layer composition of the samples down to a depth of about 50  $\mu\text{m}$ , each material indicated the same value in the content at a depth more than 3  $\mu\text{m}$  and, hence, the content distribution of the elements constituting the surface layer was analyzed based on data down to a depth of 3  $\mu\text{m}$ .

[0083] As a result, it was recognized that sample X had a concentrated region in which Cr, W, Mo and V were concentrated about two or three times those of the matrix composition at a depth of about 0.2  $\mu\text{m}$  from the surface layer, and the oxygen content close to about 30% was detected in the outermost layer. Furthermore, in the case of sample Y, W, Mo and V were concentrated about 1.5 times those of the matrix composition at a location close to the surface layer, but an element removal phenomenon was recognized with Cr. Also, the oxygen content in the outermost layer was about 6%, which is low relative to sample X.

[0084] Like sample X, it was recognized in sample Z that W and Mo were concentrated about 1.5 to 2 times those of the matrix composition at a depth of about 0.2  $\mu\text{m}$  from the surface layer, and an about 6% oxygen content was detected in the outermost layer. On the other hand, the state of Cr and V was analogous to that of sample Y, and an element removal phenomenon was recognized with the former, while the latter was concentrated in the outermost layer.

[0085] From the above, it is conceivable that sample Z has an intermediate aspect between sample X and sample Y in the concentration of the elements constituting the surface layer.

[0086] FIG. 23 depicts maximum contents of the alloying elements at a location adjacent the surface layer of each sample. As shown therein, sample X has the highest Cr, W, Mo and V contents in the surface layer. Sample Y and sample Z have substantially the same Cr content, but sample Z has higher contents of the other elements than sample Y. From these facts, it appears that the nitriding tends to increase the hardness of the samples in the order of samples X, Z and Y.

[0087] Each sample tends to be easily nitrided by the atmospheric treatment, and FIG. 24 depicts oxygen contents at the maximum content portions of the alloying elements at the location adjacent the surface layer. This graph reveals that sample X has high oxygen contents at locations other than a location having a maximum V content, compared with other samples. On the other hand, sample Y that is hard to be nitrided has lower oxygen contents than other samples. From these facts, it is assumed that the degree of difficulty in the nitriding depends upon the oxygen contents at the maximum content portions of Cr, W and Mo created at the location adjacent the surface layer.

[0088] Sample Z has the highest oxygen content at a location having a maximum V content, and the reason for this is that sample Z has the highest V content in the outermost layer, while other samples have the highest V content at a location inside the outermost layer. This is caused by a difference in oxygen absorption and is not deeply related to the V content.

[0089] According to the example referred to above, as is the case with sample X, sample Z has a surface covered with minute nitride grains deposited thereon, and the density thereof seemingly exceeds that of sample X. This determines the order of hardness in the outermost layer, and it is assumed that the minute grain deposits caused by a change in surface configuration that is in turn caused by the atmospheric treatment contributed to nitrogen absorption. It was observed that the surfaces of the sintered materials after nitriding samples X and Z were almost entirely covered with grains or protrusions of about 0.1 to 0.5  $\mu\text{m}$ .

[0090] From the above, samples X and Z can be preferably used for the wear-resistant element according to the present invention, while the use of sample Y is not preferred.

[0091] Also, the above results in the following.

[0092] (1) The surface of the material after the nitriding treatment maintains a surface state of a raw material. A large number of minute deposits are recognized on the surfaces of sample X and sample Z, while sample Y has a lesser number of deposits and is hence planar.

[0093] (2) After the nitriding, sample Z has the highest hardness at depths of 0.01 mm and 0.05 mm with sample X and sample Y following in this order. The hardness of the surface layer is closely related to the density of the deposits on the surface.

[0094] (3) The degree of difficulty in the nitriding is dominated by the content distribution of the alloying elements in the surface layer and the surface activation phenomenon of the minute oxide grains and the like.

#### INDUSTRIAL APPLICABILITY

[0095] The wear-resistant element according to the present invention is effectively used for sliding components or the



like in an engine or a compressor because the amount of processing of the soft matrix portion increases during the finishing of the wear-resistant element to thereby form minute hollows, i.e., minute oil holes and because slight wear occurs in the soft matrix portion to form the oil holes to thereby enhance the wear resistance while avoiding seizing.

1. A method of making a wear-resistant element, comprising:

shaping and sintering a material into a compact using iron-based alloy powder containing Cr; and

conducting a nitriding treatment having no carburizing action to the compact, thereby causing a surface of the compact to have a mixed structure of an Fe—Cr—N compound layer, an Fe—Cr—N diffused layer, and a matrix.

2. A method of making a wear-resistant element, comprising:

shaping and sintering a material into a compact using alloy powder in which at least one metallic element selected from Mn, Ti and V is contained in iron-based alloy powder containing Cr; and

conducting a nitriding treatment having no carburizing action to the compact, thereby causing a surface of the compact to have a mixed structure of an Fe—Cr—N compound layer, an Fe—Cr—N diffused layer, and a matrix.

3. The method according to claim 1 or 2, wherein the compact has pores formed in the surface thereof, the Fe—Cr—N compound layer being formed at locations adjacent the pores, the mixed structure of the Fe—Cr—N diffused layer and the matrix being formed at locations remote from the pores.

4. A method of making a wear-resistant element, comprising:

shaping and sintering a material into a compact using iron-based alloy powder containing Cr; and

conducting a nitriding treatment having no carburizing action to the compact, thereby causing a surface of the compact to have a mixed structure of an Fe—Cr—N compound layer, an Fe—Cr—N diffused layer, and a matrix of a sorbite structure.

5. The method according to claim 4, wherein the compact has pores formed in the surface thereof, the Fe—Cr—N compound layer being formed at locations adjacent the pores, the mixed structure of the Fe—Cr—N diffused layer and the matrix of the sorbite structure being formed at locations remote from the pores.

6. A method of making a wear-resistant element, comprising:

shaping and sintering a material into a compact using iron-based alloy powder containing Cr;

quenching and tempering the compact;

conducting a nitriding treatment having no carburizing action to the compact; and

partially removing a surface of the compact, thereby causing the surface of the compact to have a mixed structure containing at least an Fe—Cr—N compound layer.

7. The method according to claim 1, further comprising conducting an atmospheric treatment to the compact before the nitriding treatment.

8. The method according to claim 7, wherein the atmospheric treatment is conducted at a temperature of 380° C. or more.

9. A wear-resistant element comprising:

a sintered and nitrided material having a surface; and

a mixed structure of an Fe—Cr—N compound layer, an Fe—Cr—N diffused layer, and a matrix formed in the surface of the sintered and nitrided material,

wherein the surface of the sintered and nitrided material is entirely covered with grains or protrusions of 0.1~0.5  $\mu\text{m}$ .

10. The method according to claim 2, further comprising conducting an atmospheric treatment to the compact before the nitriding treatment.

11. The method according to claim 3, further comprising conducting an atmospheric treatment to the compact before the nitriding treatment.

12. The method according to claim 4, further comprising conducting an atmospheric treatment to the compact before the nitriding treatment.

13. The method according to claim 5, further comprising conducting an atmospheric treatment to the compact before the nitriding treatment.

14. The method according to claim 6, further comprising conducting an atmospheric treatment to the compact before the nitriding treatment.

15. The method according to claim 10, wherein the atmospheric treatment is conducted at a temperature of 380° C. or more.

16. The method according to claim 11, wherein the atmospheric treatment is conducted at a temperature of 380° C. or more.

17. The method according to claim 12, wherein the atmospheric treatment is conducted at a temperature of 380° C. or more.

18. The method according to claim 13, wherein the atmospheric treatment is conducted at a temperature of 380° C. or more.

19. The method according to claim 14, wherein the atmospheric treatment is conducted at a temperature of 380° C. or more.

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