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Disordering of alumina by repeated frictional contact

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Transmission electron diffraction from repeatedly rubbed α-alumina revealed a structure that was created as the sum of the contributions of several different aluminas. Owing to the lack of regularity in the atomic arrangement, this structure may not be considered as being crystalline although it is not an amorphous structure. The transformation to this state can be one of the mechanisms of plastic deformation during repeated rubbing.

1. Introduction

It has been reported that a single traverse rubbing action can cause remarkable damage to ceramics [1, 2]. Thus, it can be considered that a large number of rubbings can cause disorder in ceramics. The main purpose of this paper is to present an extremely disordered structure of alumina created by repeated rubbing. The structure is created as the sum of the contributions from several different aluminas. Although the state is not amorphous, it can not be considered to be a crystal structure owing to the lack of regularity in the atomic arrangement. The transformation to this structure acts as one of the mechanisms of plastic deformation during repeated rubbing. Another transformation produced by repeated rubbing has been reported in a previous paper [3].

2. Experimental procedure

Commercially pure sintered α-alumina (with the impurities MgO 0.3, SiO_2 0.06, CaO 0.01, Fe_2O_3 0.02, Na_2O 0.002, Wt %) was repeatedly rubbed in a unidirectional direction without lubrication, using the apparatus schematically shown in Fig. 1. Table I shows the rubbing conditions.

After repeated rubbing, the specimens were thinned by ion bombarding from the opposite side to the friction surface. These specimens were then examined

TABLE I The rubbing conditions

Rubbing speed	(mm s^{-1})	56.23
Rubbing distance/Traverse	(mm)	23
Pressure	(MPa)	296–343
Frequency	(Hz)	0.26

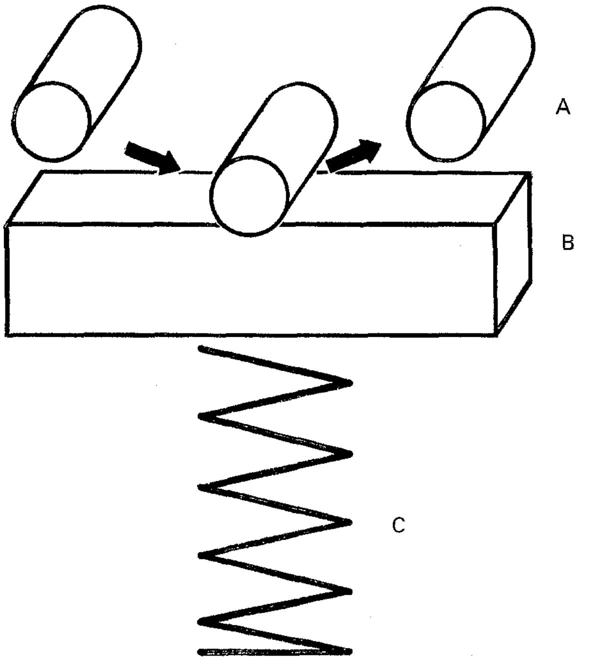

Figure 1 Schematic representation of the rubbing apparatus; A slider, B specimen, C spring.

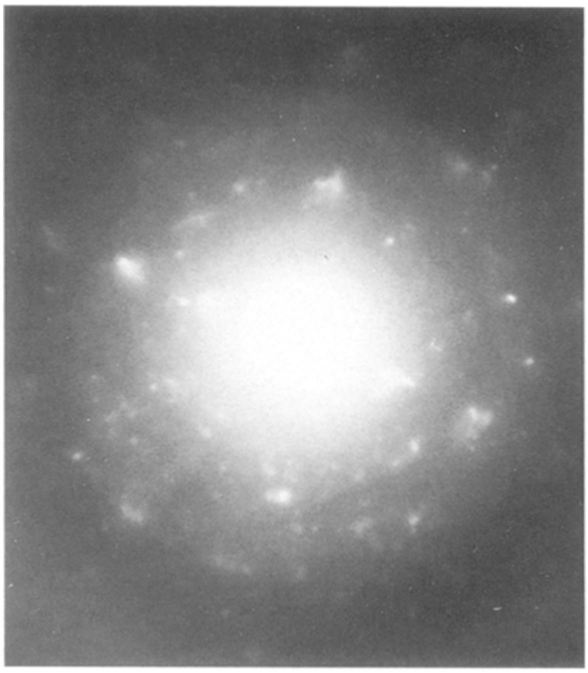

Figure 2 Transmission electron diffraction pattern from repeatedly (2×10^4 traversals) rubbed alumina.

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using a transmission electron microscope (TEM). The observed diffraction spots were indexed when the interplanar spacings and angles between planes coincided with those of known aluminas or alumina hydrates within the limits of ± 0.5 nm and ± 3.45 mrad (2°), respectively.

3. Results and discussion

Fig. 2 shows a typical TEM diffraction pattern from the repeatedly rubbed specimen. All the spots are large and not very intense. There is no *n*-fold symmetry with respect to the direct beam and all the distances from the direct spot to any other spot are unequal, in spite of the large number of spots listed in the first column of Table II. As shown in Fig. 3, only a few spots correspond with those associated with α-alumina [4]. Other spot positions partially coincide with those from other aluminas, although it should be noted that the existence or the structure of some of these aluminas are in serious doubt [5–14]. The spot positions also partly coincide with those from the aluminium hydrates tohdite ($(Al_2O_3)_5{\cdot}H_2O$) [14, 15] and akdalaite ($(Al_2O_3)_4{\cdot}H_2O$) [15] although it should be noted that the interplanar spacings in these alumina hydrates are almost equal to those in κ′-alumina [14, 15]. This coincidence of the diffraction spots does not occur for any other combinations of the various aluminium hydroxides or alumina hydrates. As is

TABLE II Interplanar spacings of spots in Fig. 2 and spots that coincide with those from unknown structural aluminas and gel one

Interplanar spacing (pm)	η-Alumina	ι-Alumina	κ-Alumina	Gel Alumina
493.53				
482.57		480.00		
387.17				391.00
380.97				
348.56				351.00
348.00		347.10		347.00
340.90				341.00, 339.00
331.99				328.00
321.71				319.00
312.85				
299.94			304.00	
297.18				
295.45				
292.83				
292.27		292.20		
290.70				
288.77				
286.86				
286.11				
285.35				
282.00	280.00	280.00	279.00	
249.60		250.00		
244.54				
243.99	240.00		241.00	
235.78		234.00		239.60
231.78		230.00	232.00	229.50
226.68	227.00			
226.20		224.00	226.00	222.70
218.69				220.40, 218.00
215.00		215.00	216.00	
212.69			211.00	
202.50		198.00	206.00, 199.00	
193.89	197.00		195.00	194.00
193.20				
190.32				
189.99				
189.16		188.00		
185.92			187.00	
184.66				
177.70		173.00	174.00	
168.34				
165.92				
165.51			164.00	
159.91		161.00		
159.32				
158.97				
156.44		155.00, 153.00	154.00	
149.46	152.00		149.00	
144.48	140.00	140.00	145.00, 143.00	
114.29	114.00			

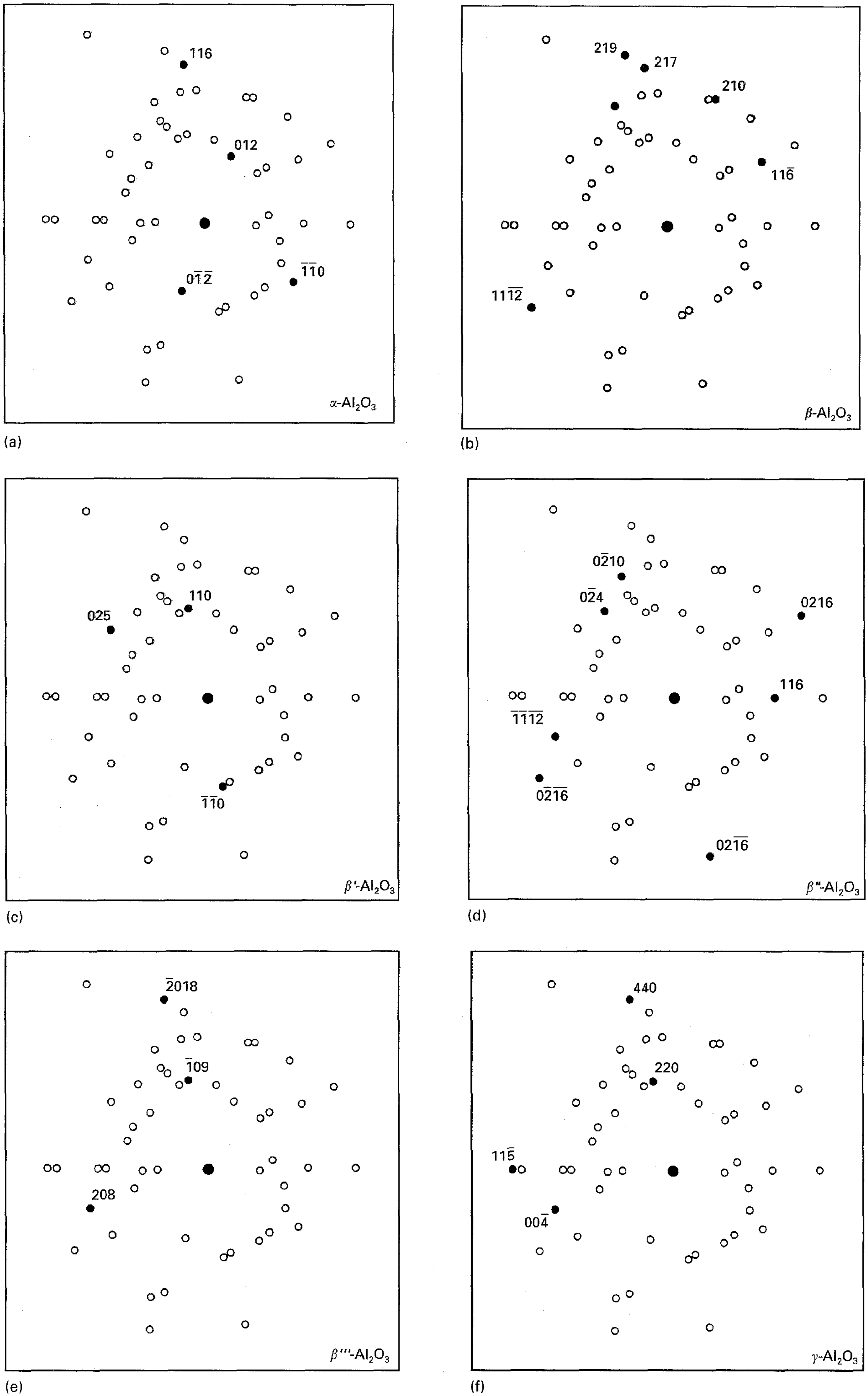

Figure 3 Schematic drawings of spot arrangement in Fig. 2: ● coincided spots, ○ uncoincided spots.

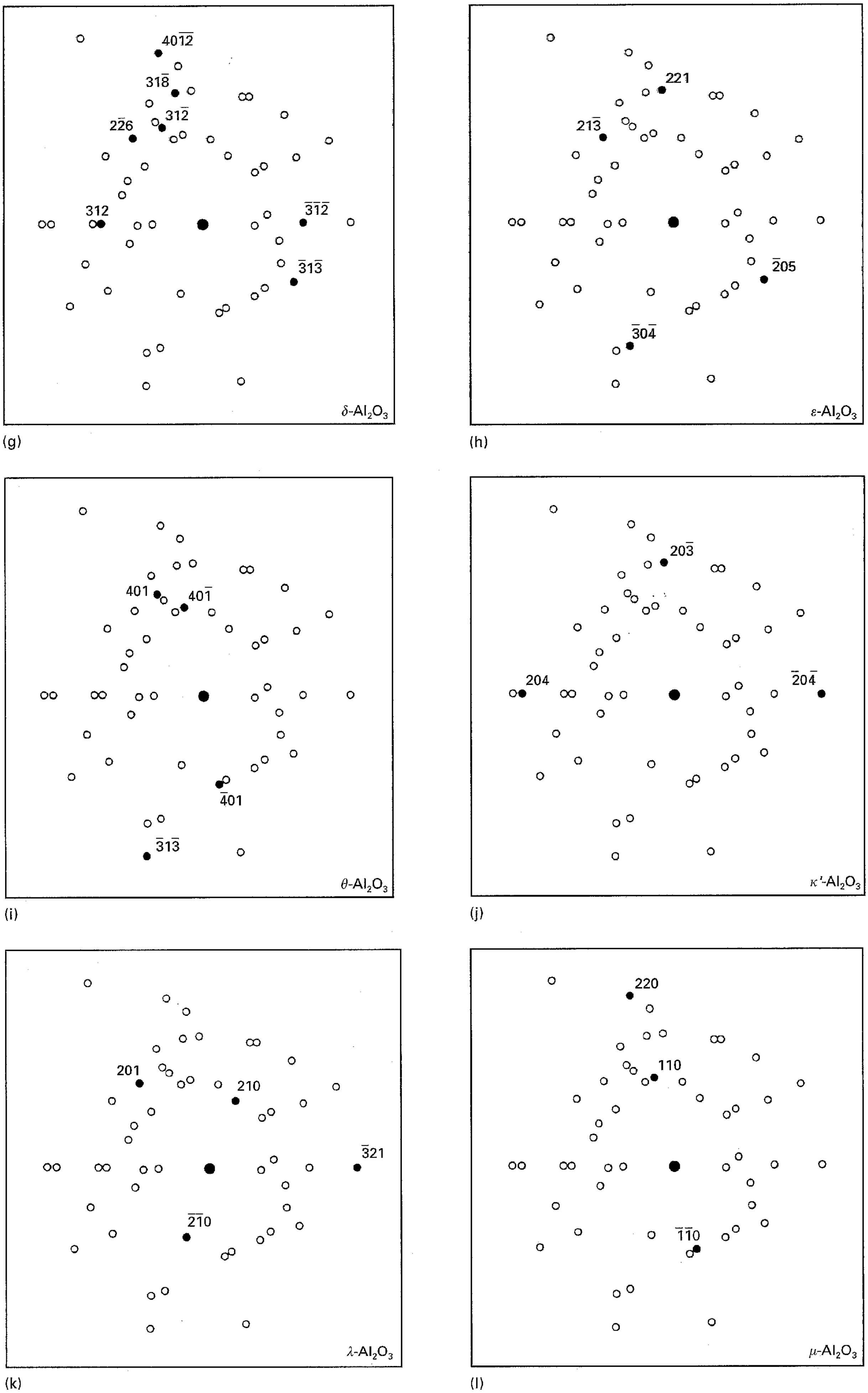

Figure 3 Continued.

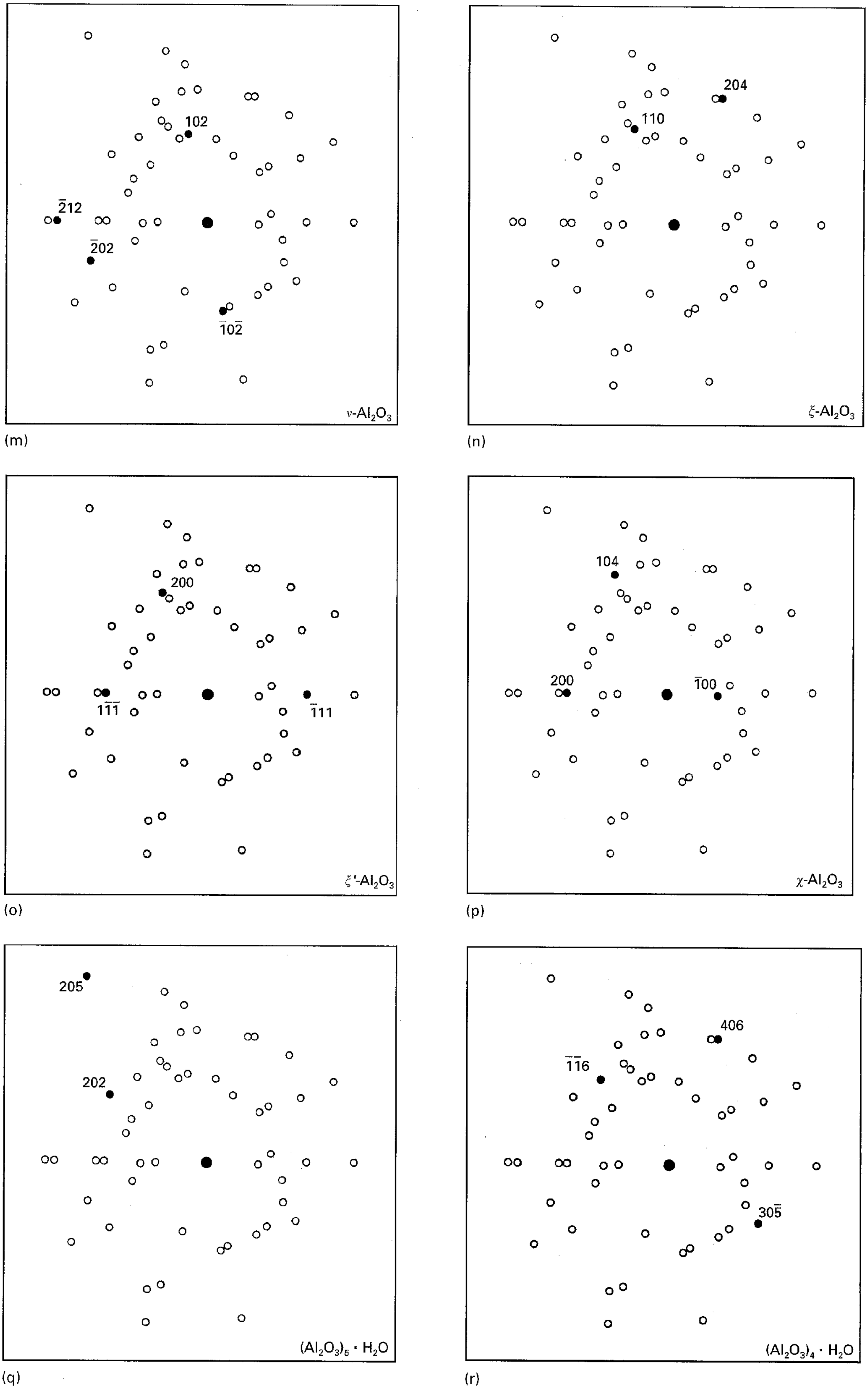

Figure 3 Continued.

shown in Table II, some interplanar spacings correspond to those expected from gel alumina [16] and also other aluminas whose structures have not yet been determined [17, 18]. These facts indicate that the α-alumina is transformed into a disordered state that is the sum of the contributions from several different aluminas. Although this state differs from an amorphous state, it lacks regularity and may therefore, not be considered a crystalline structure.

In metals, repeated rubbing reveals phenomena which are not observed after other sliding rubbing or severe working [19, 20]. Transformations, via the repeated transverse rubbing of α-alumina, different from the one presented in this paper, have been reported [3]. These transformations have not been reported in the case of usual rubbing. A large number of transverse rubbings could damage the α-alumina structure. This damage could take the form of the displacement of atoms thereby altering their atomic positions. As seen in Table II and Fig. 3, there are several metastable alumina structures, that show nearly the same interplanar spacings and angles between lattice planes. After the displacement, atoms may settle at metastable positions. This results in the above-mentioned structure which consists of parts of the structures of several aluminas. Fig. 4 is a transmission electron micrograph taken in the area where Fig. 2 was taken and it can be clearly observed that no dislocations exist in this area. We suggest that the observed transformation could be one of the mechanisms of plastic deformation during repeated rubbing of α-alumina.

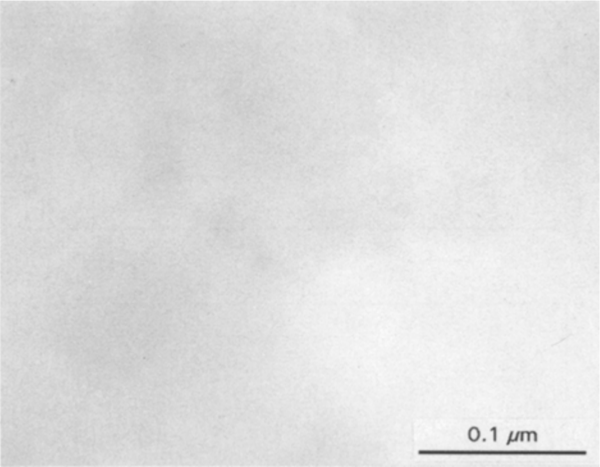

Figure 4 Transmission electron micrograph from the area where Fig. 2 was taken.

4. Conclusions

An α-alumina specimen was repeatedly rubbed with an α-alumina slider under dry conditions. A TEM diffraction pattern from the area near the friction surface of a specimen revealed the formation of a structure that could be understood in terms of contributions from several different aluminas. There is no regular atomic array in this state and therefore the state can not be regarded as being crystalline although it is not an amorphous material. The transformation to this state acts as one of the mechanisms of plastic deformation during repeated rubbing.

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