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Investigation of Mechanical and Thermal Properties of Microwave-Sintered Lunar Simulant Material Using 2.45 GHz Radiation

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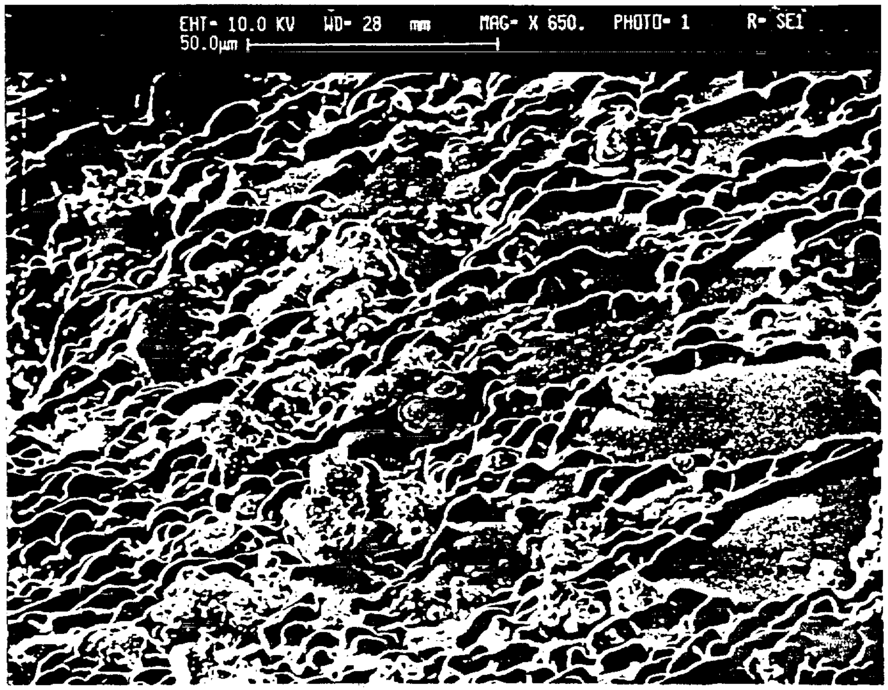
During the past year, the focus of our research was in two areas. While they may appear to be different, they are closely related. One project investigated the mechanical and thermal properties of lunar simulant material. The current status of this research is given in the following. An alternative method of examining thermal shock in microwave-sintered lunar samples is being researched. At present, a computer code has been developed that models how the fracture toughness of a thermally shocked lunar simulant sample is related to the sample hardness as measured by a micro-hardness indentor apparatus. This technique will enable much data to be gathered from a few samples. To date, several samples have been sintered at different temperatures and for different times at temperature. During the past year, a technical presentation was made on this work and a paper submitted for publication (Nehls et al. 1989). During this investigation, photomicrographs of microwave-heated samples showed what appear to be glassy regions in between grains (Figures 2.4 and 2.5). Currently, these samples are being examined using TEM techniques to determine if, indeed, the intergranular regions are amorphous. If they are, then this may help explain the apparently enhanced thermal shock resistance of microwave-sintered lunar simulant materials. Figures 2.4 and 2.5 show the fractured surface of simulant material, which is compositionally the same as Apollo 11 lunar material. Note the apparently melted intergranular regions. This phenomenon was first observed by Meek et al. (1986) in earlier microwave sintering of conventional ceramics. Earlier work on the diffusion of various metal cations in pyrex also revealed unusual nucleation characteristics when the system was heated and cooled in a microwave field (Meek et al. 1988).

It was decided to investigate (along with the above work) the melting and recrystallization characteristics of a well-studied binary system to see if the thermodynamic barrier for the nucleation of a crystalline phase may be affected by the presence of a microwave field. The system chosen was the albite (sodium alumino silicate)-anorthite system (calcium alumino silicate). Table 2.7 shows the design of the experiment. Mixtures of albite and anorthite were melted at 1400°C and then cooled to 1200°C and held for specific lengths of time in both a conventional furnace and a microwave furnace (frequency 2.45 GHz). Heating duration varied from 1 hour to 128 hours, and thermally processed samples were investigated using X-ray, microprobe, and optical polarized light techniques to determine if differences resulted from the two



Figures 2.3 SEM photomicrograph of 2A11XLB sample heated at 56,070°C per hour using 2.45 GHz radiation. Note the apparent melt regions located in between grains. Magnification 650X.

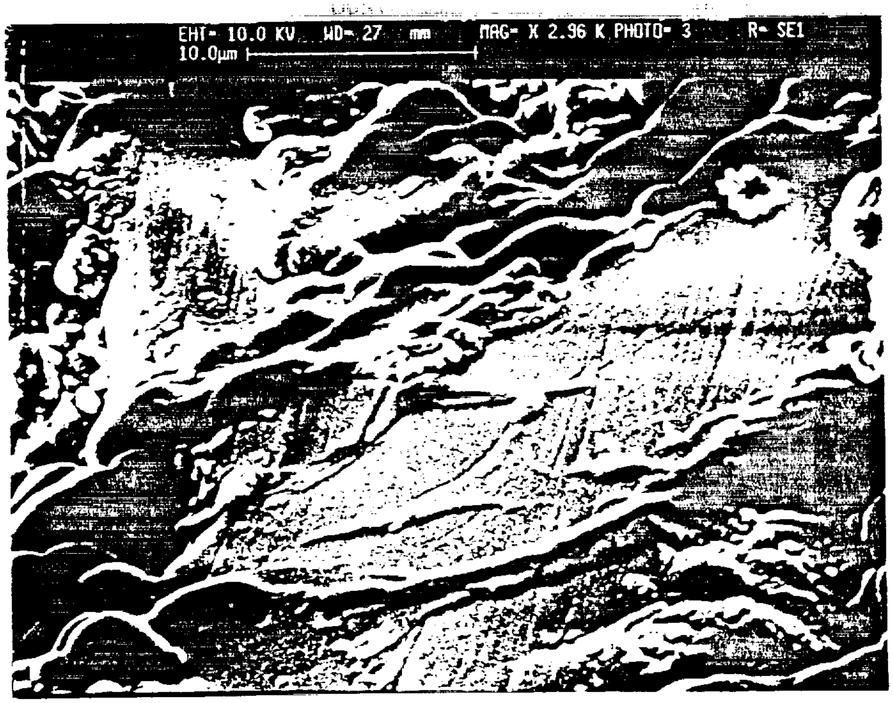


Figure 2.4 Same as Figure 2.3, but with magnification 2960X.

Table 2.7 Sample compositions and duration time at constant holding temperature in a microwave field.

Sample Composition	Holding Temperature (Degrees C)	Duration Time (Hours)
90 wt% Ab-10 wt% An	1200	1
90 wt% Ab-10 wt% An	1200	2
90 wt% Ab-10 wt% An	1200	4
90 wt% Ab-10 wt% An	1200	8
90 wt% Ab-10 wt% An	1200	16
90 wt% Ab-10 wt% An	1200	32
90 wt% Ab-10 wt% An	1200	64
90 wt% Ab-10 wt% An	1200	128
81 wt% Ab-19 wt% An	1200	1
81 wt% Ab-19 wt% An	1200	2
81 wt% Ab-19 wt% An	1200	4
81 wt% Ab-19 wt% An	1200	8
81 wt% Ab-19 wt% An	1200	16
81 wt% Ab-19 wt% An	1200	32
81 wt% Ab-19 wt% An	1200	64
81 wt% Ab-19 wt% An	1200	128
72 wt% Ab-28 wt% An	1200	1
72 wt% Ab-28 wt% An	1200	2
72 wt% Ab-28 wt% An	1200	4
72 wt% Ab-28 wt% An	1200	8
72 wt% Ab-28 wt% An	1200	16
72 wt% Ab-28 wt% An	1200	32
72 wt% Ab-28 wt% An	1200	64
72 wt% Ab-28 wt% An	1200	128

heating techniques. Figure 2.5 shows the portion of the albite-anorthite system investigated in this work.

All three conventionally heated compositions of albite and anorthite showed the presence of the crystalline α phase as shown by X-ray diffraction analysis in Figures 2.6-2.8. For the samples heated in a 2.45-GHz electromagnetic field, all compositions heated for 64 hours and the 90 wt% Ab-10 wt% An heated for 128 hours showed no trace of crystalline phase (Figures 2.9 and 2.10). For the 128-hour runs heated in the microwave field, only the 81 wt% Ab-19 wt% An and the 72 wt% Ab-28 wt% An showed a trace of crystallinity (Figures 2.11 and 2.12).

The above results show that a 2.45-GHz field affects the nucleation of the plagioclase phase in the albite-anorthite system. This effect results from the different dielectric constants of the crystalline phase and the liquid phase, respectively.

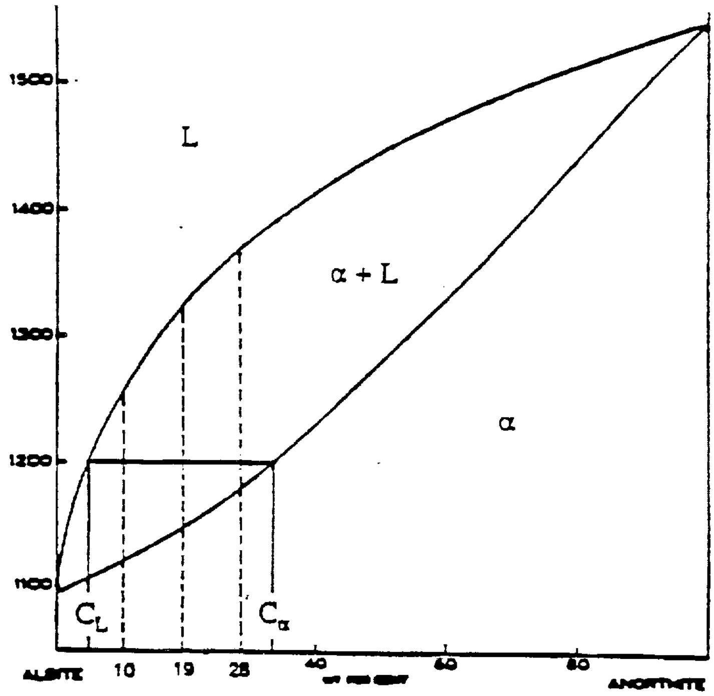


Figure 2.5 Albite-anorthite phase diagram.

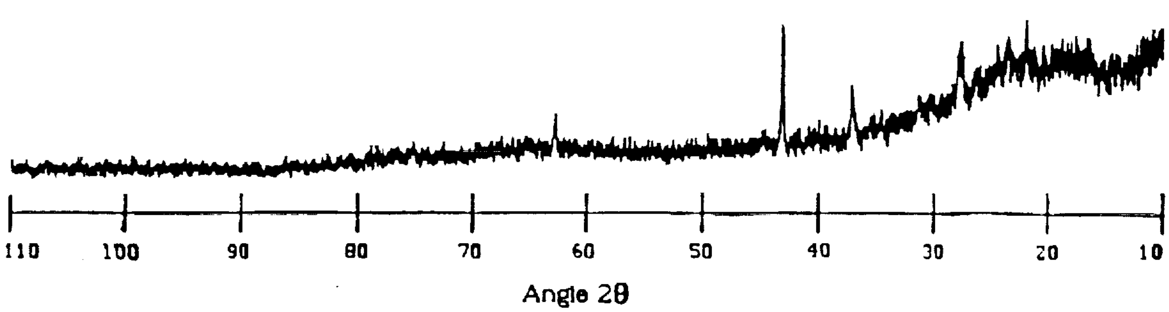


Figure 2.6 X-ray diffraction pattern of the 90 wt% Ab-10 wt% An heated in a conventional furnace at 1200°C for 128 hours.

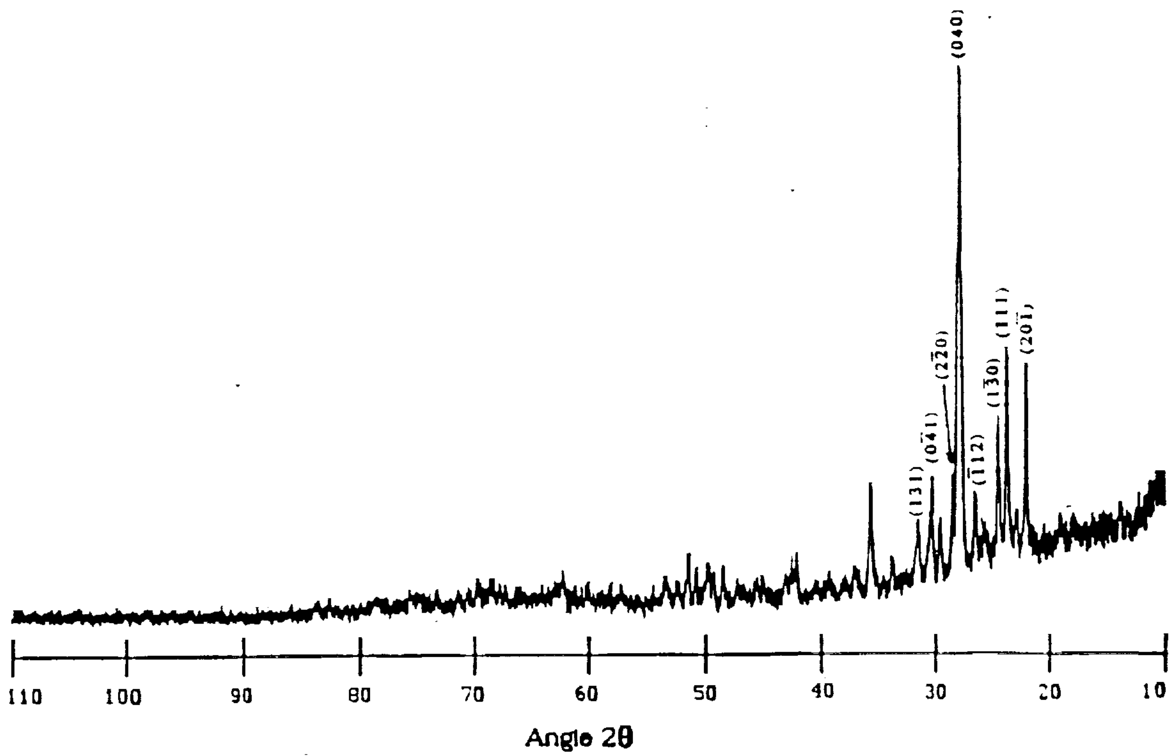


Figure 2.7 X-ray diffraction pattern of the 81 wt% Ab-19 wt% An heated in a conventional furnace at 1200°C for 128 hours.

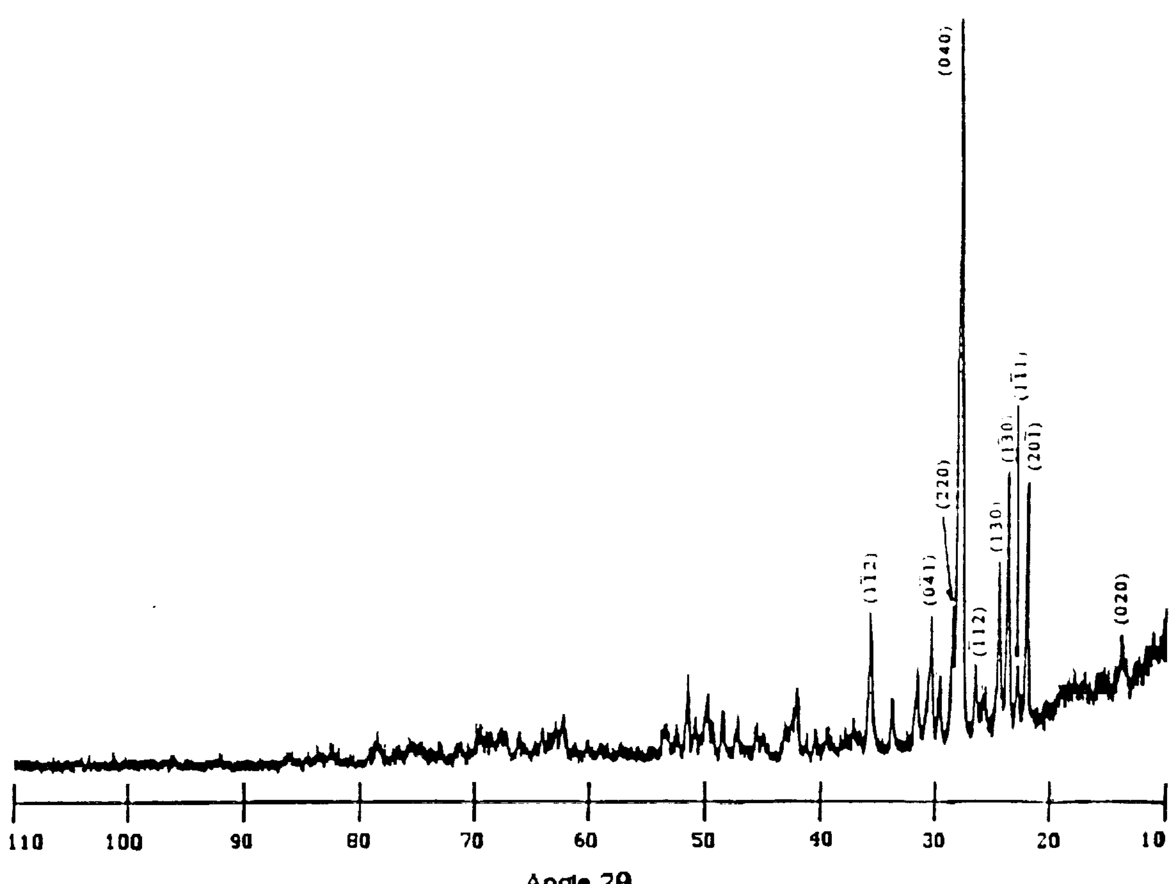


Figure 2.8 X-ray diffraction pattern of the 72 wt% Ab-28 wt% An heated in a conventional furnace at 1200°C for 128 hours.

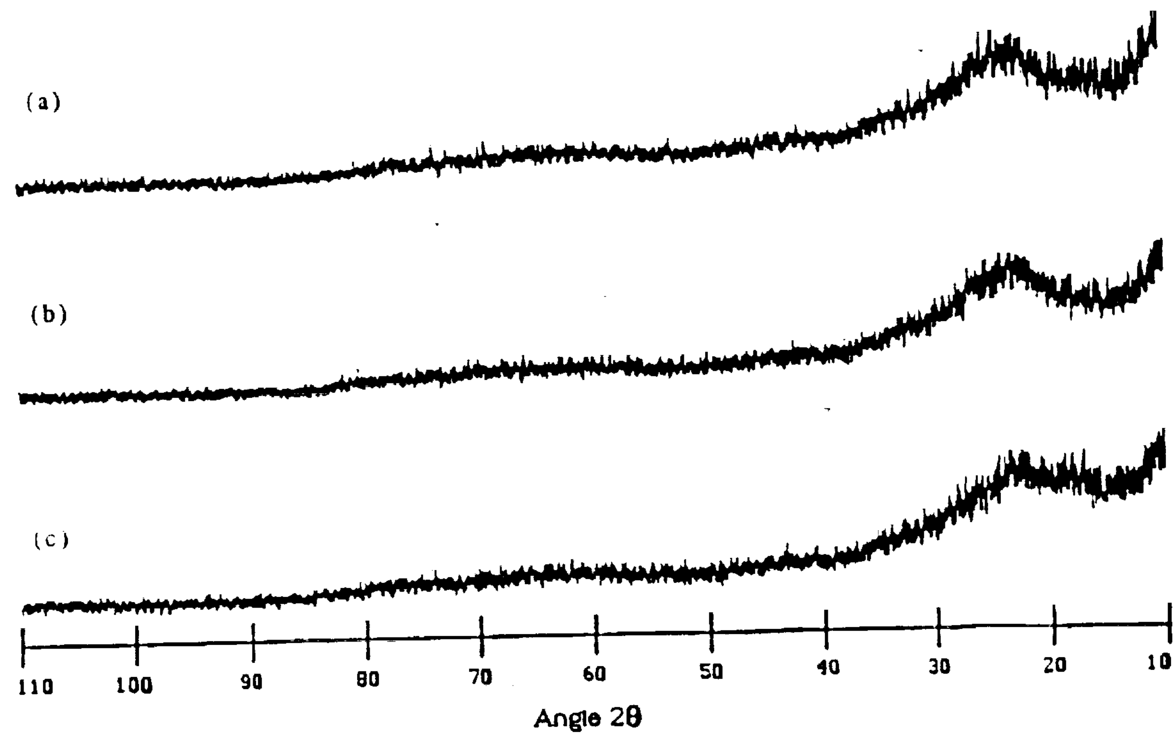


Figure 2.9 X-ray diffraction patterns of the (a) 90 wt% Ab-10 wt% An, (b) 81 wt% Ab-19 wt% An, and (c) 72 wt% Ab-28 wt% An heated in a microwave overn at 1200°C for 64 hours.

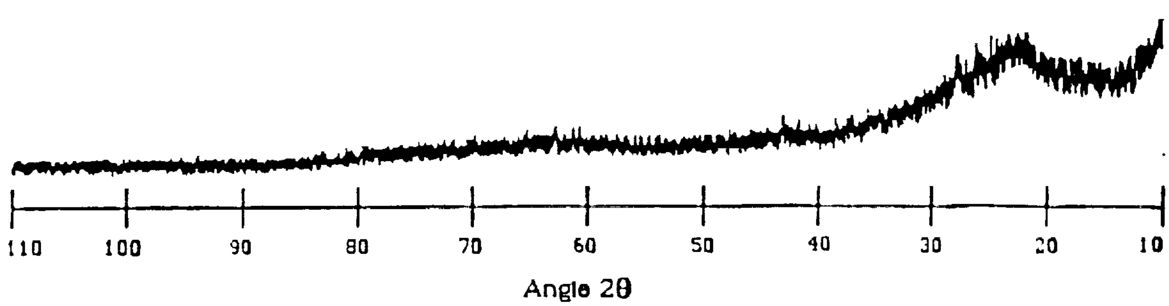


Figure 2.10 X-ray diffraction pattern of the 90 wt% Ab-10 wt% An heated in a microwave oven at 1200°C for 128 hours.

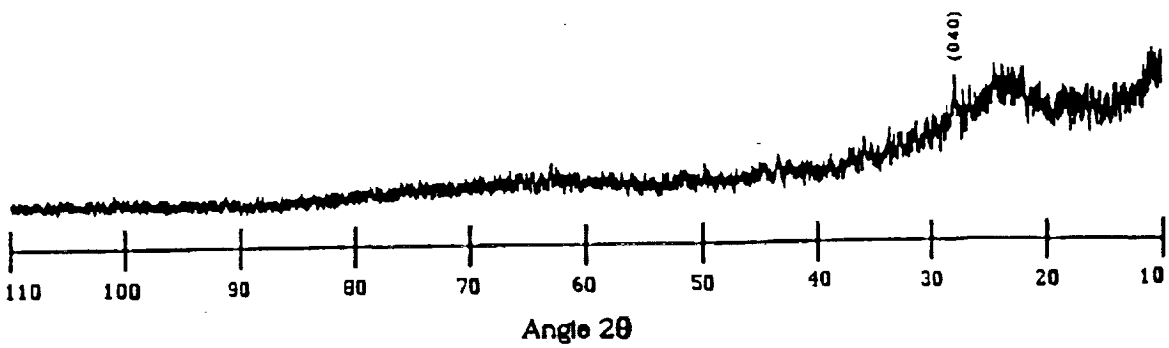


Figure 2.11 X-ray diffraction pattern of the 81 wt% Ab-19 wt% An heated in a microwave oven at 1200°C for 128 hours.

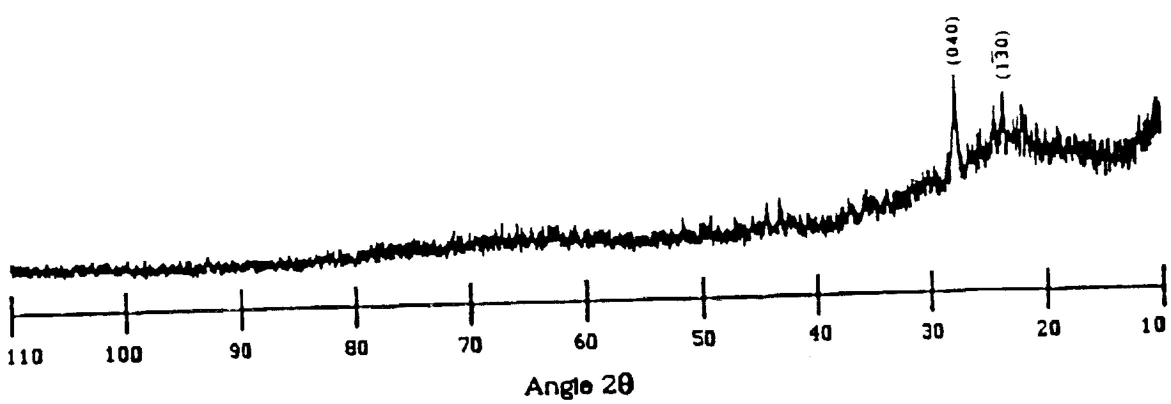


Figure 2.12 X-ray diffraction pattern of the 72 wt% Ab-28 wt% An heated in a microwave oven at 1200°C for 128 hours.

Electromagnetic field theory predicts that more power will be deposited into the lower dielectric constant region (crystalline phase) than into the higher dielectric constant region (liquid phase). This phenomenon results in the inhibition of the nucleation of the crystalline phase in the crystal-liquid two-phase region in the albite-anorthite system.

The results of this investigation suggest that all oxide-phase systems may be different when heated in a microwave field. Thus, we may expect that processing extraterrestrial materials using microwave radiation will possibly result in some different microstructures that exhibit different mechanical and thermal properties from those that are processed using conventional heating techniques.

References

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