

# Temperature Effect on the Solid-State Synthesis of Dehydrated Zinc Borates

N. Tugrul, N. Baran Acarali, A. S. Kipcak, E. Moroydor Derun, and S. Piskin

**Abstract**—Turkey has 72 % of total world boron reserves on the basis of  $B_2O_3$ . Borates that is a refined form of boron minerals have a wide range of applications. Zinc borates can be used as multi-functional synergistic additives. The most important properties are low solubility in water and high dehydration temperature. Zinc borates dehydrate above  $290^\circ C$  and anhydrous zinc borate has thermal resistance about  $400^\circ C$ . Zinc borates can be synthesized using several methods such as hydrothermal and solid-state processes. In this study, the solid-state method was applied between  $500$  and  $800^\circ C$  using the starting materials of ZnO and  $H_3BO_3$  with 1:4 mole ratio. The reaction time was determined as 4 hours after some preliminary experiments. After the synthesis, the crystal structure and the morphology of the products were examined by X-Ray Diffraction (XRD), Fourier Transform Infrared Spectroscopy (FT-IR) and Raman Spectrometer. As a result the form of  $ZnB_4O_7$  was synthesized with the highest crystal score at  $800^\circ C$ .

**Keywords**—Raman, solid-state method, zinc borate, XRD.

## I. INTRODUCTION

ZINC borates are commonly used in rubber, plastic, ceramic, paint, glass, electric insulation, wood applications, cement, and medicine as the flame retardant, smoke suppressant, afterglow suppressant, and anti-tracking agent in both halogen-containing and halogen-free polymers. Furthermore, zinc borates have been used as the preservative in wood composites, as the anticorrosive pigments in coatings, and as the polymers additives to promote char formation, suppress smoke, and retard combustion [1, 2].

Zinc borate is produced by reaction between aqueous boric acid and zinc oxide above  $70^\circ C$ . This compound has the unusual property of retaining its water of hydration at temperatures up to  $290^\circ C$ . This thermal stability makes it

attractive as a fire retardant additive for plastics and rubbers that require high processing temperatures [3].

Shi et al.[4] studied the preparation of  $2ZnO \cdot 3B_2O_3 \cdot 3H_2O$  from zinc oxide and boric acid via a rheological phase reaction. The products were characterized by XRD, TG, DTA and SEM. Moreover, the effects of experimental conditions and particle size distribution on the characteristics of the products were investigated.

Shi et al.[5] investigated  $4ZnO \cdot B_2O_3 \cdot H_2O$  nanorods synthesized by a hydrothermal route with the surfactant of PEG-300 as template. The pH value and synthetic temperature had the important influence on the composite, while the temperature and time had the effect on the morphology of products. The study on the flame-retardant property of  $4ZnO \cdot B_2O_3 \cdot H_2O$  nanorods is underway. Igarashi et al.[6] synthesized zinc borates in a two-step reaction. In the first step, zinc oxide and boric acid were combined and stirred at  $60^\circ C$  for 1.5 hours to achieve crystal formation. In the second step, the mixture was stirred continuously at  $90^\circ C$  for 4 hours, and seed crystals were added to the reaction mixture to enhance crystal growth.

In this study, the solid-state synthesis of dehydrated zinc borates between  $500^\circ C$  and  $800^\circ C$  were aimed. Synthesized products are characterized by X-Ray Diffraction (XRD) (Philips PANalytical, Xpert-Pro), Fourier Transform Infrared Spectroscopy (FT-IR) (Perkin Elmer, Spectrum One) and 400FRaman Spectrometer (Perkin Elmer Raman Station).

## II. MATERIALS AND METHODS

### A. Raw Materials and Characterization

Zinc oxide was supplied from Colakoglu Chemistry Limited Company and boric acid was retrieved from Kirka Boron Management Plant in Eskisehir.

All products were characterized by XRD, FT-IR and Raman to identify the structure and the functional groups present in the products.

The X-Ray analysis was carried out at an ambient temperature by using a Philips Panalytical X'Pert-Pro Diffraction with CuK $\alpha$  radiation ( $k = 0.15418$  nm) at operating parameters of 40 mA and 45 kV with step size  $0.02^\circ$  and speed of  $1^\circ/\text{min}$ . Phase identification of solids was performed by inorganic crystal structure database (ICSD) (Fig. 1).

The FT-IR spectrum was achieved after force was applied to the sample, pushing it onto the diamond surface. The IR spectrum was recorded in the spectral range of  $4000$  to  $650$   $\text{cm}^{-1}$  at ambient temperature and the resolution used was  $4$   $\text{cm}^{-1}$  (Fig. 2).

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For Raman Spectrometer, the parameters of exposure time (seconds) and number of exposures was set to 4. Measurement range is selected as  $3280\text{--}250\text{ cm}^{-1}$  and data interval was selected as  $2\text{ cm}^{-1}$  (Fig. 3).



Fig. 1 Philips PANalytical X-Ray Diffraction



Fig. 2 Perkin Elmer Spectrum One FT-IR Spectrometer



Fig. 3 Perkin Elmer Raman Station 400F Raman Spectrometer

#### *B. Pelletization Process*

Before the solid-state synthesis the samples were mixed homogeneously and pelletized with, Manfredi OL 57, pelletizing equipment (Fig. 4).

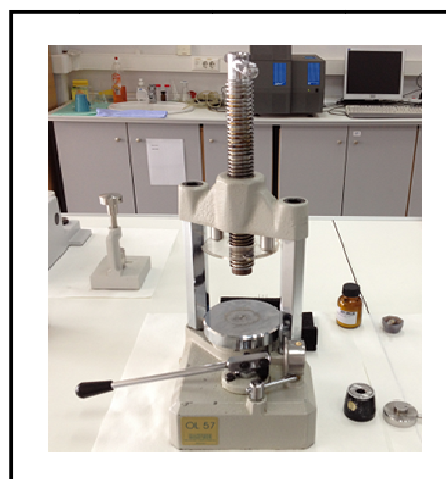


Fig. 4 Manfredi OL 57 Pelletiser

In the pelletization process, the samples were pressed at a pressure of 100 bars for the duration of two minutes. The ratios of raw materials were selected as 1:4, where first component was zinc oxide and second component was boric acid.

#### *C. Solid-State Synthesis*

After the pelletization processes, the pellets were subjected to high temperature furnace with the ceramic crucibles. The temperature increment was selected as  $10^{\circ}\text{C}/\text{min}$  and reaction time as 4 hours for  $500\text{--}800^{\circ}\text{C}$ .

III. RESULTS AND DISCUSSION

A. RawMaterial Characterization Results

XRD analysis results of raw materials were given in Fig 5-8 and Table I.

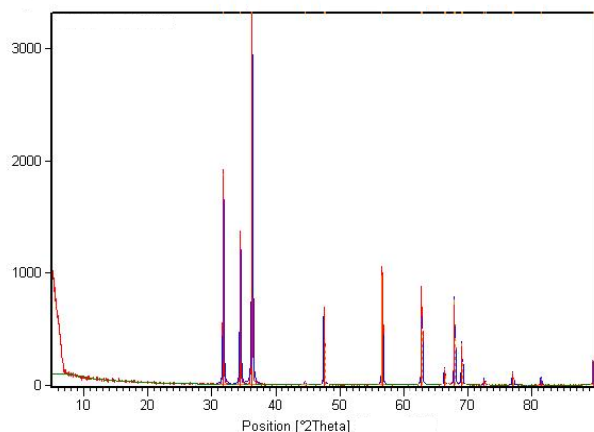


Fig. 5 XRD analysis of ZnO

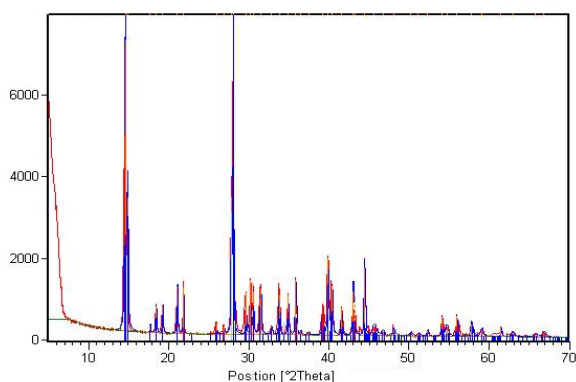


Fig. 6 XRD analysis of standard boric acid

TABLE I  
XRD RESULTS OF REACTIVES

Reference Code	Compound Name	Chemical Formula	Score
01-079-2205	Zinc oxide	ZnO	91
01-073-2158	Sassolite	H <sub>3</sub> BO <sub>3</sub>	62

From the results of the XRD analysis “01-079-2205” coded zinc oxide and “01-073-2158” coded sassolite was found.

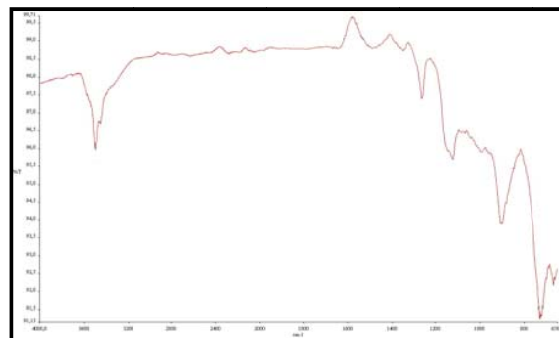


Fig. 7 FT-IR spectrum of ZnO

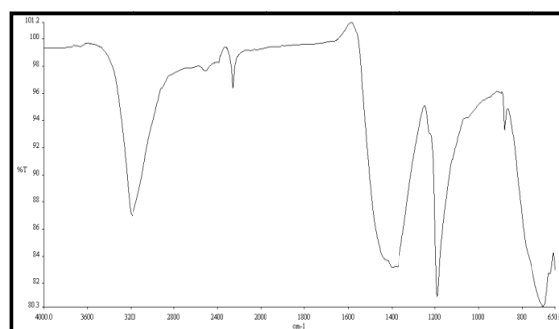


Fig. 8 FT-IR spectrum of boric acid

FT-IR spectrums were showed that the characteristic bands of the raw materials both zinc oxide and boric acid.

B. XRD Results

The XRD patterns of the products synthesized between 500°C and 800°C were given in Fig. 9 and Table II.

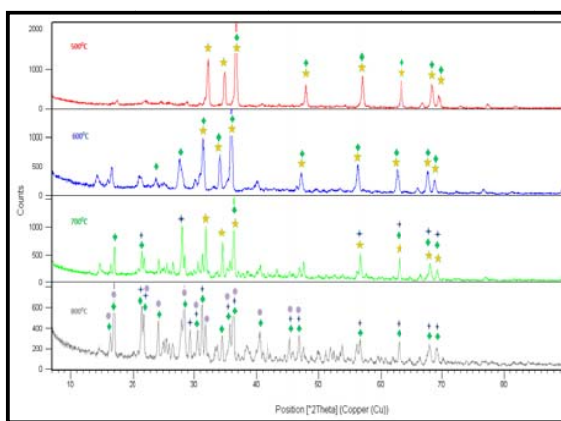


Fig. 9 XRD pattern of the synthesized zinc borates  
 01-071-0634: ▲ 00-016-0283: ●  
 01-071-2063: ★ 01-079-2205: ☆

TABLE II  
XRD RESULTS OF SYNTHESIZED PRODUCTS

Reaction Temperature	pdf no	Name	Formula	Score
500	01-071-0634	Zinc Borate	ZnB <sub>4</sub> O <sub>7</sub>	15

	01-079-2205	Zinc Oxide	ZnO	73
600	01-071-0634	Zinc Borate	ZnB <sub>4</sub> O <sub>7</sub>	32
	01-079-2205	Zinc Oxide	ZnO	75
700	01-071-0634	Zinc Borate	ZnB <sub>4</sub> O <sub>7</sub>	59
	00-004-2063	Zinc Borate	ZnB <sub>2</sub> O <sub>4</sub>	39
800	01-079-2205	Zinc Oxide	ZnO	65
	01-071-0634	Zinc Borate	ZnB <sub>4</sub> O <sub>7</sub>	69
	00-004-2063	Zinc Borate	ZnB <sub>2</sub> O <sub>4</sub>	38
	00-016-0283	Zinc Borate	ZnB <sub>4</sub> O <sub>7</sub>	64

From the results of the XRD analysis, it is seen that unreacted ZnO were seen between the temperatures of 500°C and 700°C. In the temperature of 800°C, complete formation of zinc borates were occurred. At all the temperatures the zinc borate that had a formula of ZnB<sub>4</sub>O<sub>7</sub> and “01-071-0634” powder diffraction file (pdf) were formed as major phase. The minor phase of another zinc borate formulated ZnB<sub>2</sub>O<sub>4</sub> and “00-004-2063” powder diffraction file (pdf) were formed as minor phase at the temperatures of 700°C and 800°C. The highest crystal score was seen at the temperature set 800°C with a value of 69.

### C. FT-IR and Raman Results

FT-IR and Raman spectrums of the synthesized minerals were shown in Fig. 10 and Fig. 11, the peak explanations were given in Table III and Table IV.

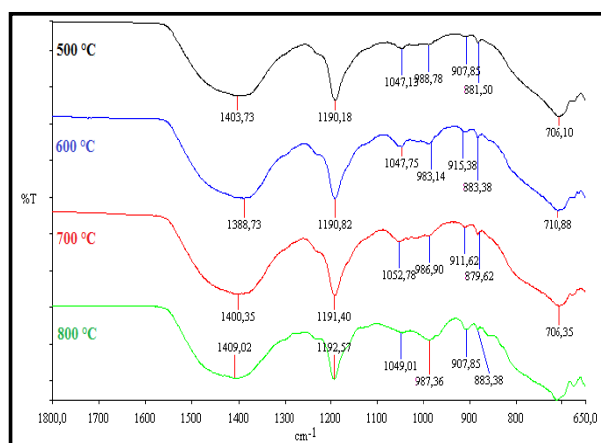


Fig. 10 FT-IR spectrums of the synthesized products

TABLE III  
FT-IR PEAK EXPLANATIONS

Peaks (cm <sup>-1</sup> )	Peak Interpretation
1600-1400	B <sub>3</sub> -O asymmetrical stretching
1400-1200	OH <sup>-1</sup> in plane stretching
1200-950	B <sub>4</sub> -O asymmetrical stretching
950-850	B <sub>3</sub> -O symmetrical stretching
850-750	OH <sup>-1</sup> out of plane stretching
750-650	B <sub>3</sub> -O stretching

At the peaks greater than 1400 cm<sup>-1</sup> were the asymmetrical stretching of three coordinate boron. Peaks at between 1192.57 and 983.14 cm<sup>-1</sup> were the asymmetrical stretching of four coordinate boron. Symmetrical stretching of three coordinate boron peaks were observed between the band values of 915.38 and 879.62 cm<sup>-1</sup>. The final peaks that were formed at about 706 cm<sup>-1</sup> were the stretching of three coordinate boron.

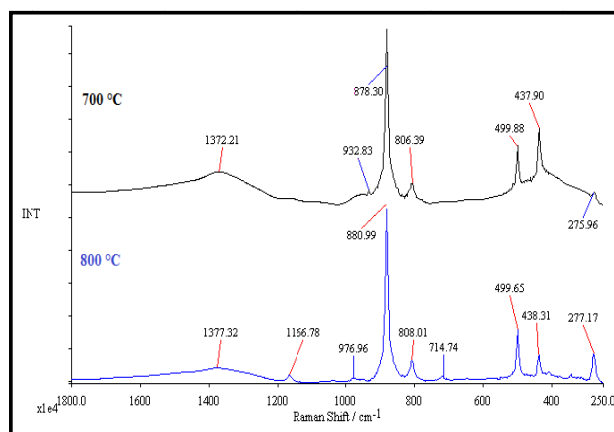


Fig. 11 Raman spectrums of the synthesized products

TABLE IV  
RAMAN PEAK EXPLANATIONS

Peaks (cm <sup>-1</sup> )	Peak Interpretation
1600-1200	B <sub>3</sub> -O asymmetrical stretching
1100-1060	B <sub>4</sub> -O asymmetrical stretching
964-872	B <sub>3</sub> -O symmetrical stretching
872-755	B <sub>4</sub> -O symmetrical stretching
755-627	[B(OH) <sub>4</sub> ] <sup>-</sup> and B <sub>3</sub> -O stretching
627-516	[B <sub>6</sub> O <sub>7</sub> (OH) <sub>6</sub> ] <sup>2-</sup> / [B <sub>3</sub> O <sub>3</sub> (OH) <sub>4</sub> ] <sup>-</sup> and [B <sub>4</sub> O <sub>5</sub> (OH) <sub>4</sub> ] <sup>2-</sup> anions, B <sub>3</sub> -O and B <sub>4</sub> -O stretching
516-300	[B <sub>3</sub> O <sub>6</sub> (OH) <sub>4</sub> ] <sup>-</sup> and B <sub>4</sub> -O stretching

The Raman spectrums of the zinc borates which were synthesized at 500°C and 600 °C, were not obtained due to their florescence effect. The florescence effect is occurred when the samples reflects the laser. These samples Raman spectrums cannot be obtained. But the zinc borates that synthesized at 700°C and 800°C were not reflected the laser so their Raman spectrums were obtained.

The peaks at around 1370 cm<sup>-1</sup> were the asymmetrical stretching of three coordinate boron. The peaks were observed at 932cm<sup>-1</sup>, 880 cm<sup>-1</sup> and 878 cm<sup>-1</sup>were the three coordinate boron symmetrical stretching. Four coordinate boron symmetrical stretching were seen at the peaks values at about 806 cm<sup>-1</sup>. [B(OH)<sub>4</sub>]<sup>-</sup> and three coordinate boron stretching were seen at 800°C reaction temperature synthesized zinc borates with a peak value of 714.74 cm<sup>-1</sup>. Final peaks were due to the [B<sub>3</sub>O<sub>6</sub>(OH)<sub>4</sub>]<sup>-</sup> and four coordinate boron stretching.

## IV. CONCLUSION

Zinc borate (ZB) is a multifunctional fire retardant

containing different proportion of zinc/boric oxides and having high dehydration temperature. The characterization results of XRD, FT-IR and Raman showed that at the temperatures of 500°C through 700°C, solid-state zinc borate syntheses were not completed. But at the temperature of 800°C, the formations of zinc borates were completed. At all the temperatures the formation of "01-071-0634" coded zinc borate ( $ZnB_4O_7$ ) was the major phase among the zinc borates. The crystal score of  $ZnB_4O_7$  were the highest at the 800°C.

From The FT-IR and Raman results of the products showed the characteristic peaks of the dehydrated zinc borates were obtained.

studies and studied on the synthesis of magnesium borates from different raw materials and wastes at the Ph.D. Also he is improving the neutron shielding studies with the synthesized materials and working on the element analysis of Turkish Teas and Coffees. Another research field about the studies he is working is the zinc borate synthesis.



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