Hydrated Magnesium Borate Synthesis from MgCl₂·6H₂O at 80°C by Hydrothermal Method

A. S. Kipcak, P. Gurses, E. Moroydor Derun, and S. Piskin

Abstract—Borate minerals have attracted considerable attention in the past years due to their structural chemistry and mechanical properties in several industries. Recently, increasing attention has been paid to the use of; synthetically produced magnesium borates as catalysts reinforcing material for plastics, the conversion of hydrocarbons, electro-conductive treating agent, anti-wear and anti-corrosion materials. Magnesium borates can be synthesized by several methods such as; hydrothermal and solid-state (thermal) processes. In this study the hydrothermal production method was applied at the modest temperature of 80°C along with convenient crystal growth. Using MgCl₂·6H₂O, H₃BO₃, and NaOH as starting materials, 30, 60, 120, 240 minutes of reaction times were studied. After all, the crystal structure and the morphology of the products were examined by X-Ray Diffraction (XRD) and Fourier Transform Infrared Spectroscopy (FT-IR). As a result the forms of “Admontite” and “Mcallisterite” minerals were synthesized.

Keywords—FT-IR, hydrothermal method, magnesium borates, XRD.

I. INTRODUCTION

BORATE minerals have many potential application areas due to their structural chemistry and mechanical properties [1]. So far, many kinds of borate systems have been widely studied according to their special useful areas as well as to their form of presence such as; being in nature or synthesizing in the laboratory [2]. Magnesium borates have become an attractive support for the use of synthetically produced magnesium borates as catalysts reinforcing material for plastics [3], wide band gap [4], also anti-wear, and anti-corrosion materials [5].

The synthesis of magnesium borates occur using several methods such as hydrothermal and thermal processes [6]. Most of these methods for synthesizing magnesium borate need multistep, involving liquid or gas phase processes as well as long reaction periods and high energy needs [7]-[9]. Therefore, it is necessary to develop a simple, cost effective technique to prepare magnesium borate powders. Considering all above mentioned points and due to the effect in minimizing thermal strain in crystals, hydrothermal production method was applied with a modest temperature in order to secure better nucleation control [10], [11]. The basic principle of this process is to use heat energy to induce chemical reaction and change material structure as well as properties.

Before conducting the experiment, the studies in literature were investigated thoroughly. In the study of [12], MgBO₂(OH) nanowhiskers were produced with hydrothermal method by using MgCl₂·6H₂O, H₂BO₃, and NaOH as raw materials at 200°C for 12h. Using the raw materials MgCl₂·6H₂O, H₂BO₃, and NaOH, [13] produced [MgBO₂(OH)] with the reaction parameters 240°C and 18h. After the synthesis with hydrothermal method, magnesium borate hydroxide was calcined in order to obtain Mg₂B₂O₅ nanowhiskers. Keeping the molar ratio Mg: B:Na as 2:3:4, MgBO₂(OH) was synthesized using MgCl₂, H₂BO₃ and NaOH as starting materials in the study of Reference [14]. The isothermal condition was kept at 240°C for 18h.

The aim of this study is to synthesize hydrated magnesium borates using MgCl₂·6H₂O, H₂BO₃, and NaOH with hydrothermal synthesis method used in the above-mentioned literature studies. Differently from the used reaction parameters in literature, shorter reaction times (30, 60, 120, and 240 minutes) and decreased reaction temperature (80°C) were applied in our experiments. XRD and FT-IR spectroscopy analysis were used to identify the synthesized magnesium borate powders.

II. EXPERIMENTAL

A. Raw Material Preparation and Characterization

Boric acid (H₃BO₃) was supplied from the Eti Bank Bandırma Boron and Acid Plant in Balıkesir, Turkey. Then it was crushed, ground with agate mortar (Fig. 1 (a)) and sieved (Fig. 1 (b)) to a particle size below 75 microns.

The other raw materials, magnesium chloride hexahydrate (MgCl₂·6H₂O) and sodium hydroxide (NaOH) were provided from Sigma-Aldrich and Merck Chemicals, respectively, both with 99.9% purity.

Boric acid powders were subjected to X-Ray Diffraction (XRD) analysis, Philips PANalytical brand (Fig. 2) with Cu-Kα radiation at the parameters of 45kV and 40mA was used [15].

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material structure as well as properties. After the reaction, the mixture was filtered through the filter paper and the mixture below the filter paper was dried in a dryer at 40°C. Finally, the solid was washed thoroughly with pure alcohol (96%), supplied from Merck Chemicals, in order to remove any excess boric acid content. The purified white precipitate was dried in Ecocell model oven again at 40°C, and finally collected for characterization analysis.

C. Characterization of Synthesized Magnesium Borates

The crystal structure and the morphology of the products were examined by X-ray diffraction (XRD), Fourier Transform Infrared Spectroscopy (FT-IR) with the parameter sets aforementioned before.

III. RESULTS AND DISCUSSION

A. Raw Material Characterization Results

XRD results and pattern of H$_3$BO$_3$ were shown in Table I and Fig. 5, respectively.

<table>
<thead>
<tr>
<th>Raw Material</th>
<th>Reference Code</th>
<th>Mineral Name</th>
<th>Mineral Formula</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boric acid</td>
<td>01-073-2158</td>
<td>Sassolite</td>
<td>H$_3$BO$_3$</td>
<td>62</td>
</tr>
</tbody>
</table>

Table I: XRD Results of H$_3$BO$_3$
The XRD pattern of boric acid shown in Fig. 4 was well matched to the standard diffraction pattern of Sassolite with powder diffraction file (pdf) number “01-073-2158”. FT-IR spectrums of the boric acid, magnesium chloride hexahydrate and sodium hydroxide were shown in Fig. 6 and Table II, respectively.

The FT-IR spectra of NaOH exhibited the following absorptions and they were assigned referring to the literature [16]. The band at around 3600 cm⁻¹ is assigned as the characteristic peak of O-H tension from OH⁻ groups. From the FT-IR analysis, the spectrums were scanned with the FT-IR ATR inorganic library and the results are given in Table II.

According to the results boric acid and magnesium chloride hexahydrate were verified.

The XRD patterns of all the samples presented the similar profiles. “01-076-0540” and “01-070-1902” pdf numbered “Admontite” and “Mcallisterite” minerals were formed at two reaction times of 30 and 60 minutes. As the reaction time increased from 30 minutes to 60 minutes, the score of Mcallisterite minerals raised, whereas the score of Admontite minerals decreased noticeably. Because formed Admontite mineral structure was turned to Mcallisterite form.

As the reaction time increased from 60 minutes to 120 and 240 minutes, Admontite peaks were disappeared. It indicated that pure Mcallisterite minerals were obtained with the reaction times at 120 and 240 minutes. It can also be seen that the Mcallisterite score increases and peaks become sharper at 240 minutes, which is indicative of better crystallization that can be seen in the XRD crystal scores.

C. Synthesized Magnesium Borate FT-IR Results

FT-IR peak list and spectrums of the samples were shown in Table IV and Fig. 8, respectively.

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### Table II

<table>
<thead>
<tr>
<th>Score</th>
<th>Library Code</th>
<th>Mineral Name</th>
<th>Mineral Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.704</td>
<td>A10031</td>
<td>Boric acid</td>
<td>H₃BO₃</td>
</tr>
<tr>
<td>0.864</td>
<td>A10084</td>
<td>Magnesium chloride hexahydrate</td>
<td>MgCl₂·6H₂O</td>
</tr>
</tbody>
</table>

### Table III

<table>
<thead>
<tr>
<th>Reaction Time</th>
<th>Pdf #</th>
<th>Mineral Name</th>
<th>Mineral Formula</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>01-076-0540</td>
<td>Admontite</td>
<td>Mg(B₂O₃)(OH)₂·7H₂O</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>01-070-1902</td>
<td>Mcallisterite</td>
<td>Mg₂[(B₆O₇)(OH)₆]₂·9H₂O</td>
<td>83</td>
</tr>
<tr>
<td>60</td>
<td>01-076-0540</td>
<td>Admontite</td>
<td>Mg(B₂O₃)(OH)₂·7H₂O</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>01-070-1902</td>
<td>Mcallisterite</td>
<td>Mg₂[(B₆O₇)(OH)₆]₂·9H₂O</td>
<td>86</td>
</tr>
<tr>
<td>120</td>
<td>01-070-1902</td>
<td>Mcallisterite</td>
<td>Mg₂[(B₆O₇)(OH)₆]₂·9H₂O</td>
<td>83</td>
</tr>
<tr>
<td>240</td>
<td>01-070-1902</td>
<td>Mcallisterite</td>
<td>Mg₂[(B₆O₇)(OH)₆]₂·9H₂O</td>
<td>90</td>
</tr>
</tbody>
</table>

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### Table IV

<table>
<thead>
<tr>
<th>Product Code</th>
<th>30 min</th>
<th>60 min</th>
<th>120 min</th>
<th>240 min</th>
<th>Peak Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak 1</td>
<td>1411.64</td>
<td>1411.97</td>
<td>1410.92</td>
<td>1411.09</td>
<td>vₐ(B₃O₃-O)</td>
</tr>
<tr>
<td>Peak 2</td>
<td>1337.36</td>
<td>1337.28</td>
<td>1336.97</td>
<td>1336.73</td>
<td>vₐ(B₃O₃-O)</td>
</tr>
<tr>
<td>Peak 3</td>
<td>1240.39</td>
<td>1241.86</td>
<td>1240.44</td>
<td>1240.10</td>
<td>δ(B-O-H)</td>
</tr>
<tr>
<td>Peak 4</td>
<td>1055.38</td>
<td>1056.29</td>
<td>1054.96</td>
<td>1055.09</td>
<td>vₐ(B₄O₄-O)</td>
</tr>
<tr>
<td>Peak 5</td>
<td>965.74</td>
<td>966.22</td>
<td>965.02</td>
<td>965.40</td>
<td>vₐ(B₃O₃-O)</td>
</tr>
<tr>
<td>Peak 6</td>
<td>857.72</td>
<td>857.97</td>
<td>857.53</td>
<td>857.50</td>
<td>vₐ(B₄O₄-O)</td>
</tr>
<tr>
<td>Peak 7</td>
<td>811.92</td>
<td>812.44</td>
<td>811.61</td>
<td>810.92</td>
<td>vₐ(B₄O₄-O)</td>
</tr>
<tr>
<td>Peak 8</td>
<td>671.55</td>
<td>671.86</td>
<td>670.84</td>
<td>671.12</td>
<td>γ(B₃O₇O)</td>
</tr>
</tbody>
</table>
As seen from the results, the FT-IR spectrums of the samples were assigned referring to literature [7], [8], [17]. According to Fig. 6, peak 1 between band values 1411.97 and 1410.92 cm\(^{-1}\) was due to the asymmetric stretching of B(1)-O. Also, peak 2 was assigned to this formation. The band value between 1241.86 and 1240.10 cm\(^{-1}\) was in-plane bending of B-O-H. Peak 4 and peak 6 can be contributed to the B(4)-O asymmetric stretching vibrations in the value of 1056.29 - 1054.96 cm\(^{-1}\) and 857.97-857.50 cm\(^{-1}\), respectively. In addition, the symmetric stretching vibration of the B(3)-O was observed between 966.22 and 965.02 cm\(^{-1}\), for peak 5. Peak 7 band 1410.92 cm\(^{-1}\) was due to the asymmetric stretching of B(3)-O. Lastly, peak 8 can be attributed to the bending of three coordinate boron with bands between 671.86 and 670.84 cm\(^{-1}\).

IV. CONCLUSIONS

With the conducted experiments, it was aimed to research the influence of the reaction time on the synthesized product. With this target, certain reaction parameters, such as mole ratio of raw materials, reaction temperature and drying temperature were selected and determined with pre-experiments. As seen from the outcomes of XRD analysis, increasing reaction time from 30 minutes to 240 minutes proved that the score of Mcallisterite minerals rose gradually. Increasing time to 120 and 240 minutes, the structure of Admontite minerals turned to Mcallisterite structure, which indicated pure Mcallisterite minerals were formed. However, at the reaction time of 240 minutes, sharper peaks and better crystal structure were monitored comparing to other reaction times.

From all the results, it is nearly the same in all the recorded FT-IR spectra of magnesium borates. In addition, the results of FT-IR analysis represented nearly the same band values of characteristic peaks of Magnesium Boron Hydrates. Comparing to the other literature studies, our results with more pure magnesium borate powders demonstrate that this hydrothermal production method we use is not only a simple and cost-effective way but also a technique which is helpful in the synthesis of other magnesium borates.

### REFERENCES


Pelin Gurses was born in Istanbul in 1988. Gurses graduated B.Sc. in Chemical Eng. Department at Yildiz Technical University, Istanbul, in 2011. She is currently continuing M.Sc. education at the same university. Gurses is interested in synthesis and characterization of magnesium borate minerals and derivatives. She is working as a Product Development Engineer at Mercedes Benz Türk Bus Plant, as well.
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Emek Moroydor Derun was born in Istanbul in 1976. Moroydor Derun was graduated from B.Sc. in 1998, M.Sc. in 2000 and Ph. D. in 2005 from Chemical Engineering Department at Yildiz Technical University, Istanbul. Her research interest is in the area of waste management, lightweight concrete, semi conductive materials and boron technology. She has many articles and studies in international and national conference proceedings and articles.

Sabriye Piskin graduated from Istanbul Technical University on Chemical Engineering with M.Sc. degree in 1974. She completed a Ph.D. degree at the same department in 1983. Her research interests include boron minerals and compounds, hydrogen storage technologies, fuel cell applications, materials characterization, coal, waste management, corrosion, implants and synthetic materials production.