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Processing and characterization of redmud reinforced polypropylene composites

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Abstract. In this work, the redmud reinforced polypropylene composites were fabricated by compression molding setup. The effects of the redmud content on the mechanical, melting and crystalline behavior of the composites was investigated. The melting and crystalline behavior of the composites were investigated using Digital Scanning Calorimeter. The test results show that hardness of the composites increases with increasing redmud content while incorporation of redmud content decreases tensile and impact strength of the composites. It is determined that the addition of redmud on the polypropylene does not affect the crystalline behavior of the composites.

1. Introduction
The application of polymer based composites is unlimited and finds wide application in automotive structural parts, and they are also used as packaging materials for electronic industries among other applications [1]. To meet the demand of industrial requirements, the composites are mainly fabricated using natural and synthetic fiber. Nowadays, natural and synthetic fiber composites are finding huge application because of their good strength-to-weight ratio. Most natural composites are fabricated using thermoset and it is found that they possess good mechanical, thermal and tribological properties [2]. In case of thermoplastics, processing of composites is simple and a high production is achievable with lower production cost. Polypropylene is widely used as a matrix material because of its excellent cost to weight ratio and addition of reinforcement significantly improves the mechanical, thermal and tribological properties [3].

Recently, there is increased demand for green and renewable substitutes for organic and inorganic filler [4]. The availability of organic and inorganic filler is abundant in nature. The proper selection of filler will decide the mechanical, thermal and tribological properties of the composites. On the other hand, there are also materials that are pollutant to the environment and are not effectively utilized. Among the various industrial waste materials, the most hazardous materials are redmud. Redmud is the waste product obtained during the production of industrial alumina from bauxites. Bayer’s process is the most efficient and suitable process for producing alumina. It is noted that for the production of one ton of alumina, it requires 1.5 to 2 ton of bauxite. About 0.7 ton of redmud is produced during the process, which is stored into an empty dry land [5]. The storing of the redmud causes environmental pollution and affects the land quality. To overcome these issues, there are significant attempts made by
researchers to effectively use this particular waste material into useful products. Among others, some of the attempts include minerals recovery, production of low cost bricks and special cements [6]. The redmud contains huge amount of oxides of alumina, ferric and silica. These elements could be better reinforcement materials for the improvement of the mechanical properties of the composites.

The fabrication of composites is done by many ways. The most popular methods are melt mixing, injection and compression molding. In case of injection, the handling of short fiber is easier and it is possible to produce good composites. However, the handling of long fiber is difficult and the resultant properties may not be as expected. Meanwhile, compression molding is simple and the handling of long, short and particulate is not difficult. The composite obtained through this method is superior in mechanical and tribological properties. Dike et al. (2013) have developed the B$_4$C filler reinforced polypropylene composites by twin screw and injection molding method. The fabricated composites are tested for its mechanical and tribological properties, and it is found that addition of the reinforcement increases the hardness and yield strength of the composites. On contrary, the incorporation of B$_4$C decreases the wear resistance of the composites during the dry sliding wear test [7]. Reza et al. (2013) studied the effect of clay nano composites on polypropylene matrix materials. The composites are fabricated by the process of melt mixing. It was noticed that the addition of nano particles increases the Young’s modulus and the yield strength of the composites [8]. Gummadi et al. (2012) fabricated composites using fly ash as reinforcement in polypropylene matrix. The composite fabricated by vertical injection molding process by twin heating method. It was concluded that the addition of the reinforcement reduces the flexural strength and modulus of the composites [9]. Ramadevi et al. (2015) fabricated treated abaca fibers and benzenediazonium chloride treated abaca stands polypropylene composites using injection molding method. The prepared composites were tested for tensile, impact and flexural properties and it was found that untreated fiber composites possess good mechanical properties than the untreated composites [10]. It was noted from the experimental result of Yang et al. (2007) that the tensile strength of rice-husk flour reinforced polypropylene composites decreases with addition of the reinforcement while at the same time, an increase in tensile strength of the composite was found when proper compatibilizing agent was used [11].

In this work, an attempt is made to fabricate redmud reinforced polypropylene composites using compression molding setup and the fabricated composites are tested for their mechanical, melting and crystallinity properties.

2. Experimental details

2.1. Materials
Polypropylene in the form of pellets with a density of 0.905 gm/cm$^3$ was purchased from Oxford Chemical Industries, Mumbai, India and it was used as the matrix materials. Redmud was used as the filler material and it was obtained from NALCO, Odisha, India.

2.2. Fabrication of composites
The received redmud was crushed in ball mill for two hours and it was sieved to obtain uniform size particulates. The size of the particulates is in the range of 4 µm. The revised polypropylene matrix materials were crushed in the pulverizer to get uniform size particulates, which were almost equal to the size of the reinforcement. The average size of the redmud reinforcement and polypropylene matrix was 4 µm. Figure 1 and Figure 2 depict the received polypropylene and redmud, respectively. Redmud reinforced polypropylene composites were then fabricated using the compression molding setup. The required quantity of matrix material and reinforcement was taken and blended for one hour to obtain better mixing. The temperature of the mold was maintained at 200+100°C, and it was compressed to the pressure of 200kg/cm$^2$. After one hour, the composite within the die was allowed to cool to the room temperature and the final composite material was taken after 24 hours. The size of the fabricated composite was 100 x 100 x 3 mm.
2.3. Tensile testing
The tensile behavior of the composite was evaluated in accordance with the ASTM standard D3039 using DTRA 30kN twin screw, Deepak Polyplast machine. Size of the specimen used for the tensile test was 220 x 13 x 13 mm and 5 mm/min was maintained as the feed rate.

2.4. Impact testing
ASTM D256 was used to conduct the impact test for the fabricated composite material using Deepak Polyplast digital impact testing machine. Size of the composites for impact test was 65 x 15 x 3 mm. The impact strength of the composites was measured in terms of Joules.

2.5. Hardness testing
Hardness of the composites was measured as per ASTM D2240 using Shore D hardness tester, HT 6510D. The average value of three tests was reported for all the tests.

2.6. Melting temperature and degree of crystallinity
Differential Scanning Calorimeter (DSC) of METZSCH STA–1100M type was used to identify the crystallization state of the composites. Digital Scanning Calorimeter was used to study the physical transitions of the composites in terms of heat flow of the samples as function of temperature. The samples were tested at ambient condition and by gradually increasing the temperature of the sample up to 800°C. The heating and cooling rate was maintained at 10 °C/min. Crystallinity of the composites was measured from the DSC curve, theoretical heat fusion of the unreinforced polypropylene and the mass fraction of the composites.

3. Result and Discussion

3.1. Tensile strength
Figure 3 shows the effect of redmud addition on the tensile property of the composites. It is observed from the experimental results that the addition of redmud in the polypropylene decreases the tensile strength of the composites, which was reduced from 28.55 MPa to 26.53 MPa. The reduction in tensile strength of the composites could be attributed to the lack of stress transfer ability of the reinforcement materials. Similar result was also observed by Oksman et al. (2009). It is established that the reduction of tensile strength is due to the poor adhesion between the matrix and reinforcement. Other reason for decreasing tensile strength of the composites is due to the agglomeration of the reinforcement in the matrix materials since size of the redmud particulate is in the range of 4 µm.
3.2. Hardness strength

Figure 4 shows the effect of redmud on the hardness of the composites. Interestingly, the addition of redmud from 0 to 15% increases the hardness of the composites in marginal level only. For instance, the hardness of the composites is increased by only 3% compared to the neat PP. It is also evident from the result of tensile modulus that the increase in tensile modulus is due to the effect of increase in hardness. As also can be clearly observed from the results of the tensile test is that the tensile strength of the composites is reduced while increasing the redmud content. The reduction in tensile strength is due to the incorporation of redmud, which influences the elongation and plasticity of the composites, and the increase in hardness is due to the effect of redmud addition into the matrix. Figure 5 shows the distribution of redmud over the neat PP.

Figure 4. Effect of redmud on hardness of the composites

3.3. Impact strength

From Figure 6, it is evident that the impact strength of the composites is decreased when increasing the amount of reinforcement. The reason for this decrease in impact strength is attributed to the low affinity between the matrix and the reinforcement, which is due to low Vander Waals force between...
the matrix and reinforcement phase. The reduction in Vander Waals force reduces the load transfer ability of the composites, thus impact strength of the composites is reduced gradually. An increase in the redmud content also lowers the impact strength because of its braking and splitting property during loading. Due to this reason, the filler material fails to resist sudden applied force and in turn reduces the impact strength of the composites.

![Figure 6. Effect of redmud on impact strength of the composites](image)

### 3.4. Melting temperature and degree of crystallinity

Crystalline phase of the composite material plays a vital role in deciding the mechanical properties of the fabricated composite materials. The polypropylene is in the form of semi-crystalline in nature. The portion of the crystalline phase influences the mechanical properties of the composite materials. Thus it is important to study the effect of redmud on the changes in the crystalline structure. Figure 7 shows the DSC melting curves of polypropylene and its redmud reinforced polypropylene composites.

![Figure 7.](image)
The addition of redmud to polypropylene does not influence the melting properties of composite materials. It is also observed from the DSC curve that the melting temperature of redmud reinforced composite slightly shifts to lower temperature when increasing the redmud content. The reason for the slight reduction in melting temperature is the effect from the reduction of lamellar thickness of crystallites. It is realized that the addition of redmud reduces the crystallinity of the composite materials as compared to neat polypropylene. This is attributed to the more crystalline nature and less amorphous part of the polypropylene, which provides opportunity for redmud to accommodate in the interlamellar spaces.

4. Conclusion
In this work, redmud reinforced polypropylene composites were successfully fabricated using the compression molding setup. The mechanical, melting and crystalline behaviors of the composites were studied. It has been found that the addition of redmud to the polypropylene composites increases the hardness of the composites significantly, but there is a drop in tensile strength and impact strength of the composites. Furthermore, the addition of redmud reinforcement slightly reduces the melting and crystalline properties of the composites.

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