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Overview of Simulation in Wood Plastic Composites Manufacturing

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Abstract

Objectives: This paper presents a review on the application of simulation software as a tool aiding in design and manufacturing aspect of wood plastic composites (WPCs). The scope of application of models present in literature by previous researchers is discussed in general. **Methods/Statistical Analysis:** A review on the simulation in wood plastic composites manufactured by compression moulding process is presented by analyzing the data present in literature. Important factors which affect the mechanical properties of final wood plastic composite products are stated. This paper also addresses the challenges of application of simulation models for prediction of mechanical properties of wood plastic composites by other researchers. **Findings:** Simulation models related to wood based composites are discussed and their applicability for wood plastic composites is reported. A need of simulation software for WPC prediction purpose and easy to use by other researchers is highlighted. **Application/Improvements:** Importance of collaborative efforts between material researchers and computer science researchers is also highlighted to fulfill the need of the simulation software in wood plastic composite area.

Keywords: Compression Moulding, Manufacturing Process, Simulation, Wood Plastic Composites

1. Introduction

Global warming is a concern which cannot be overlooked by the researchers and scientist community while developing new products. It is causing immense concern among the scientists, and forcing the development of the environment friendly materials and products in order to contribute in reducing the impact of global warming. Following the trend to reduce carbon emissions composite industries are now looking for futuristic alternatives such as bio-based composites to contribute in limiting carbon footprints by reducing the use of petroleum based products. Composite materials which are made by adding natural wood fibers as fillers in plastic matrix are known as Wood Plastic Composites (WPCs). Besides fibers being natural, their good mechanical properties attract them as a good filler choice with plastic matrix to obtain the benefits of the natural fibers. All constituents of the composite materials retain their own properties. Hence, the final mechanical properties of the composite depend upon mechanical properties of the wood fibers themselves[1]. WPCs are in great demand globally as one of the popular choice in the area of composites. Around the world, many countries are producing WPCs, North America is one of the major producer, second is Asia Pacific and then Europe. Building and construction has been reported as the major area of application of WPCs and constitute biggest share of the WPC market, by application in 2015[2]. A report by global demand for WPCs mentions that WPC worth around 3.3 billion USD in 2014, and is reported to touch around 6.0USD billion mark in 2020[3]. On the other hand about 190,000 tonnes of WPC were produced in Europe only for the construction area in 2012[4]. Furthermore according to the demand this number is expected to increase up to 400,000 t in 2020. In order to follow-up with the growth rate, it is necessary to produce high performance and increased durability product. Wood plastic industry is comparatively a new industry in the area of composites and many researchers are involved in investigation of this composite[5,6].

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Scientist often needs to conduct experiments, involving the study of many parameters and it is quite hard to put so much time and cost and in conducting the experiments on each set of parameters. Furthermore, this approach has the limitations such as the results of experiments are only valid for a specific set of parameters. To study effect of another parameter, experiments should be conducted again. This procedure could be very exhausting, time talking and expensive. In addition, this process leads to rejection of small amount of material due to low quality end product. The reason behind this may be that the effect of internal parameters and processing variables is not known on resultant product[7]. Hence to reduce such wastage and optimization of product it is important to investigate WPCs and gain insight to understand the effects of different parameters and processing on final product, computer modeling and computer simulation is suggested as a reliable approach to assist scientist in exploring the parameter space[8].

This paper focuses on a short review, for use of computer simulation in prediction of WPC properties and compression moulding manufacturing process. Several important variables which have a significant impact on final mechanical properties of the WPCs are discussed in the paper. It also highlights the challenges this industry is facing due to limited availability of suitable simulation software for WPC. In the end the summary of the paper is concluded.

2. Manufacturing of WPCs

Compression moulding involves pressing of the composite material between two hot metal plates during the manufacturing of the wood based composites where the wood fibers and plastic matrix are heated to promote resin curing and compression of mat[9].

Study of press cycle is a keen interest area for researchers as it directly affects properties of the resulting WPC. So it is necessary to rigorously control all the processing variables to improve product quality and to optimise pressing time. Hence, it is highly viable to improve the quality of WPC, for which important aspects of proper curing of matrix and manufacturing of the composite materials should be taken into consideration[10]. Compression moulding seems a fairly simple manufacturing process however it can be quite difficult to visualize the mechanism happening inside the material during the pressing[7,11], failure to understand can lead to weak strength and quality issues in the final product and rejection of the end product.

3. Influencing Parameters

In order to follow-up with the growth rate and global demand, it is necessary to produce high performance and increased durability products. WPCs are still comparatively quite new in composites field. WPCs are manufactured by addition of wood fibers into plastic matrix on high temperatures. Hence, the resultant properties of the composite mainly reply on the strength properties of the fibers and the matrix[1] along with other processing parameters.

Fiber volume fraction is a parameter used for modelling purpose to define the amount of fibers into the composite. Strength properties are the function of fiber volume fraction, and hence they are directly proportional to fiber volume fraction. However, it has been established that when the fiber volume fraction was very high, there was a decrease in composite properties due to not enough matrix to bind the fibers[12].

Fiber orientation or arrangement of fibers in the matrix also contributes significantly in determining the mechanical properties of the WPC. The manner of arrangement of wood fibers with respect to other fibers, concentration and distribution of fibers, everything influence composite strength and various other properties of composites significantly[13].

Length of fiber is another significant factor that contributes to mechanical properties of WPCs more specifically, known as aspect ratio[14]. Aspect ratio is understood to be the ratio between diameter and length of the wood fibers.

The bonding between fibers and the matrix is termed as interfacial adhesion. In technical words the chemical bonding between the two materials is often stated as interfacial bonding. Week WPC properties are often a result of poor internal bonding between the thermoplastic matrix and the wood fibers. To address the week bonding between the two materials coupling agents are employed to enhance the bonding between the natural fibers and the plastic matrix. This improves the adhesion between fibers and thermoplastic matrices in WPC production, and the process of adding these coupling agents is termed as “chemical coupling” or “compatibilizing[15,16].

Another method employed to improve the chemical bonding between the fibers and matrix is known as "chemical treatment/modification" and often used for removing lignin from fibers. In[9] studied the effects of alkali treatment on few natural fiber based composites, i.e., linen, flax and bamboo fabric reinforced epoxy resin and have positive results. Hence consideration of this parameter in the modelling can lead to more accurate prediction of composite properties.

In simple words curing is a term associated with the change of a state of material from liquid to solid. In[10] reported that quality production of composite materials is dependent on press cycle during the molding process which results in uniform curing as well as uniform compaction. Curing is an important aspect during compression moulding and plays an important role on the quality of the final product. It was also reported[17] that there is an increased demand for simulation methods and fundamental models that consider a time or degree of cure dependence of mechanical properties for the prediction of mechanical behaviours during curing process.

As all the parameters discussed above and many more processing variables influence the final WPCs properties, specific modelling should be done to incorporate as many parameters as possible in the models or simulation software to study and improve understanding through predictions.

4. Challenges in Simulation of WPC

The demand for new products and designs has forced manufacturers and scientists to create products with the best quality with optimized production cost in order to sustain in the competitive market. However, designing and testing new products are processes that are lengthy and time consuming, and besides, they involve a lot of money. Furthermore due to lack of comprehensive understanding of the influence of various parameters and processing conditions, sometimes, the end product is wasted due to quality defects, such as low mechanical strength, improper curing, etc. Despite continuous substantial effort in the area of characterization of WPCs, modelling of these biocomposites poses important challenge. The major hindrances identified are the inherent complexity of individual wood particles/fibers and the composite interaction between the wood particles and the plastic on the micro mechanical level[18].

During compression molding, optimization of processing time is an important factor to ensure proper curing and good quality product. However, there are only a few simulation models applicable in the area of wood composite industry, and there are no reports found for their suitability to WPC. Nonetheless, most of the time, modeling and simulation codes have limitations, as the commercial codes may not exist. Sometimes, modeling efforts are not integrated with user-friendly interfaces to suit the industry or laboratory use[8]. There are problems associated with the understanding of the effects of various parameters on the final product, and these in turn, lead to quality issues. Thus, in order to gain insight, simulation software have been proven to be helpful in visualizing the effects of temperature and curing of matrix inside the board[7,19,20]. Hence, in order to improve the quality of WPC, the important aspects of proper curing of matrix and manufacturing of the composite materials should be taken into consideration[10]. Furthermore to reduce the wastage in industries and laboratories, computer modeling and simulation was suggested as a reliable approach to assist scientist in exploring the parameter space[7,11,17]. Simulation software can be helpful to gain additional understanding of the composite as through simulation software it is easy to visualize and understand the effects of some of the parameters which are difficult to visualize otherwise. For this to happen the models should be integrated with graphical user interfaces.

In[21] reported a one dimensional heat transfer model for prediction of temperature changes which take place during the manufacturing of WPC by hot press molding. This model applied finite difference method to compile the coding performed in MATLAB for obtaining the numerical solution of the heat transfer problem. This non-linear transient heat transfer model was reported suitable to predict the temperature changes inside WPCs boards made from wood flour with PP and HDPE plastics during compression moulding. Therefore, the model could be successful to study pressing times for various combinations of wood and plastic materials. Furthermore, this model could be used as an aid for design of optimized hot press operation of the WPCs. However this research work lacks the integration with GUI because of which it cannot be applicable by other researchers. Beside that another researchers developed two models, one-dimensional and three-dimensional, in studying the curing simulation of Hemp fiber-acrylic based composites to simulate the hot pressing process[22]. They applied the

Finite Element Method (FEM) using software and their results were compared with the Finite Difference Method (FDM). Besides, the Crank Nikolson method was applied to obtain the solution for the problem. Other than that, In[23] studied the curing behaviour of hemp and kenaf fiber based HDPE composites and proposed a one dimensional model for prediction of temperature profile and the curing behaviour. They used finite difference numerical method for solving the heat transfer problem. However their work cannot be applied to other WPCs as the equations were developed for specific materials such as hemp and kenaf wood fibers. Moreover none of the above mentioned models can be utilized successfully for simulation and prediction of the WPCs manufacturing without further modification in these models. Besides most of them also lack GUI which makes them extremely difficult for other researchers and industry people to use them. One of the recommendation to solve this problem is that material science researchers and computer science experts work together to develop suitable software for WPCs and other materials.

5. Conclusion

A review of current simulation work in the area of WPC manufactured by hot pressing is presented. The scope of the current available simulation models was discussed. It is observed that there lot of work is going on for investigating WPCs, however not significant amount of attention is paid on simulating the WPC properties manufactured compression moulding process. Some work has been reported in modelling compression moulding process but for every new combination of materials the researcher need to model and simulate the composites themselves. Simulation models are hard to understand and apply without GUI. It was observed that most of the modelling work was left after successful validation of the models. Most of the models were not integrated with GUIs. It is important to make efforts in the direction to integrate the modelling work with GUI to make it comprehensively useful. The International Conference on Fluids and Chemical Engineering (FluidsChE 2017) is the second in series with complete information on the official website[24] and organized by The Center of Excellence for Advanced Research in Fluid Flow (CARIFF)[25]. The publications on chemical engineering allied fields have been published as a special note in volume 3[26]. Host being University Malaysia Pahang[27] is the parent governing body for this conference.

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