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Manufacturing of wood plastic composite board from Karanja (*Pongamia pinnata*) : A statiscal experiment design approach

Md. Rejwan Bari

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সেমিনার লাইব্রেরী

Manufacturing of wood plastic composite board from Karanja (*Pongamia pinnata*) : A statistical experiment design approach

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Dedicated

To

My Beloved Parents

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Abstract

Karanja (*Pongamia pinnata*) is locally distributed mostly in southern part of our country which is excellent source of Biodiesel. Owing to its versatility, wood is used in WPC production as raw material. Therefore, wood–plastic composite (WPC) is an environmentally progress way of combining plastics and wood flour. The composite typically consists of three major elements: wood flour, thermoplastic plastics, filler or coupling agent or lubricant. The physical and mechanical properties of WPCs highly depend on the material formulation, and the optimal material composition is an essential topic of current research. As why, a statistical design is performed. This study investigated the effects of material compositions on the physical and mechanical proper-ties of WPCs. Here, WPCs manufactured using polypropylene (PP) plastics and wood flour. The study evaluated three parameters: (1) the mass ratio of wood and PP; (2) pressing time; and (3) talc percentage as filler, where pressure and temperature is remain constant. Maintaining wood content at 30% or less produced the best mechanical properties, and wood content above approximately 70% resulted in reduction of all physical and mechanical properties of WPCs. The results showed that pressing time has a great impact on board quality. The optimal concentration of the filler content (talc) in WPCs is 2.5%. Adding the proper amount of talc can improve the mechanical properties and significantly reduce the shrinkage-swelling, but over-dosing significantly affect all the properties of the WPCs. The study demonstrated that Box-Behnken design as response surface methodology (RSM) with desirability function is attained to predict the adequacy of the design and optimization of the process parameters for the WPC production.

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1.1 Background of the Study

Wood plastic composite (WPC) is a product which could be obtained from plastic and wood. WPC is a composite with a rapid growing usage consisting of a mixture of wood waste and polymeric material (Soury et al. 2009). The term WPCs refers to any composites that contain plant (including wood and non-wood) fibers and thermo-sets or thermoplastics. Thermosets are plastics that, once cured, cannot be melted by repeating. These include resins such as epoxies and phenolics, plastics with which the forest products industry is most familiar. Thermoplastics are plastics that can be repeatedly melted. This property allows other materials, such as wood fibers, to be mixed with the plastic to form a composite product. Polypropylene (PP), polyethylene (PE) and polyvinyl chloride (PVC) are the widely used thermoplastics for WPCs and currently they are very common in building, construction, furniture and automotive products (Panthapulakkal et al. 2006).

Wood plastic composites (WPC) are a new generation of the composites experiencing considerable growth in production and demand in many countries. A wide range of polymers; such as polypropylene, polyethylene, polyesters, etc as well as lignocelluloses; such as wood flour, wood fibers, hemp, linen, etc are used for their production.(Jiang et al. 2003 & John, 2004)

Plastic and wood wastes have been a main environmental concern. Plastic is the biggest problem due to its high amount of waste generated, non biodegradability and the fastest depletion of natural resources regarding its short life cycle, therefore increased amount of material utilized in its production, and waste generated. The same applies to wood with lesser degree where it is depleting trees and forests and the wastes mainly are either burned or disposed; resulting in extra consumption, depletion, and pollution of nature. Several worldwide attempts have been adopted; especially in the developed countries, to take advantage of these types of waste especially with the raised need for alternatives to virgin materials (Winandy et al. 2004).

WPC has become currently an important address of research that gained popularity over the last decade especially with its properties and advantages that attracted researchers such as: high durability, Low maintenance, acceptable relative strength and stiffness, fewer prices relative to other competing materials, and the fact that it is a natural resource (Bengtsson and Oksman 2006) & (Winandy et al. 2004). Other advantages have been strength points including (Wechsler and Hiziroglu, 2007): the resistance in opposition to biological deterioration especially for outdoor applications where untreated timber products are not suitable, the high availability of fine particles of wood waste is a main point of attraction which guarantees sustainability, improved thermal and creep performance relative to unfilled plastics where It can be produced to obtain structural building applications including: profiles, sheathings, decking, roof tiles, and window trims.

Wood plastic composites have found commercial success in exterior applications. Scientific investigations of these materials have concentrated, mainly, on improving mechanical properties. While wood plastic composites may have good rot resistance, few scientific studies on the biodegradation of these materials have been carried out. Laboratory procedures for evaluating the decay resistance of wood products are common but they are not without problems because they are more severe than most above ground field exposure tests. Also some tests may be unsuitable for composites. The main concerns are the unknown impact of the differences between solid wood and composites with regard to decay, susceptibility to moisture gradients and increased surface area to volume ratio of composite panel products. (Wolcott and Englund, 1991)

In this study *Pongamia pinnata* species are used as wood flour in WPC board producing. But no more study has been carried out with such species. Therefore the study has carried out to determine the optimum manufacturing conditions to manufacture wood plastic composite board from *Pongamia pinnata* using response surface methodology (RSM) as a statistical experimental design. A set of experiments were developed by employing Box-Behnken design to the optimization of analytical methods, considering their advantages such as a reduction in the number of experiments that need be executed resulting in lower reagent consumption and considerably less laboratory work (Ferreira et al. 2007). Thus, the main objective of this study is to determine the effects of the selected factors interactions in the WPC board production analyzed with a design of experiments (RSM) and statistical modeling approach.

1.2 Objective of the Study

The objectives of this study are-

- To optimize the processing parameters for producing wood plastic composite board from *Pongamia pinnata*.
- To determine the effect of processing parameters on physical and mechanical properties of producing wood plastic board.
- To predict the mathematical model equation for producing desired quality board.

2.1 Wood

2.1.1 Physical composition

Wood (xylem fiber) is composed of elongated cells; they are oriented in the longitudinal direction of the stem (Figure 2.1). The ends are connected through openings, and these openings are called pits. These cells vary in function and differ in shape. They perform in the transport of liquid and act as food reserves. They also provide necessary mechanical support to the tree. (Eero Sojstrom, 1993)

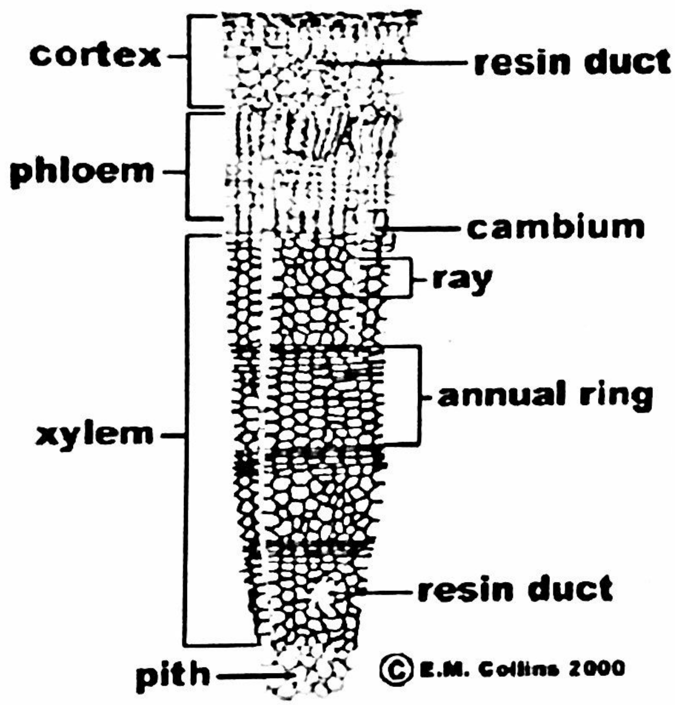

Figure 2.1. Diagram showing a section of a dicot stem.

2.1.2 Xylem Ultra structure

The xylem cells consist mainly of cellulose, hemicellulose, and lignin. Cellulose is comprised of a crystalline structure, while hemicellulose has a semi-crystalline structure and lignin is an amorphous polymer. The cell wall is built up by several layers, namely the middle lamella (ML), primary wall (P), outer layer of the secondary wall (S_1), middle layer of secondary wall (S_2) and warty layer (W) (Figure 2.2). These layers differ from each other based on their chemical composition and their structure. The ML is located between the cells and serves the function of binding wood cells together. Though it contains pectin in the initial stages it becomes lignified in later stage of life (Fengel and Wegener, 1983).

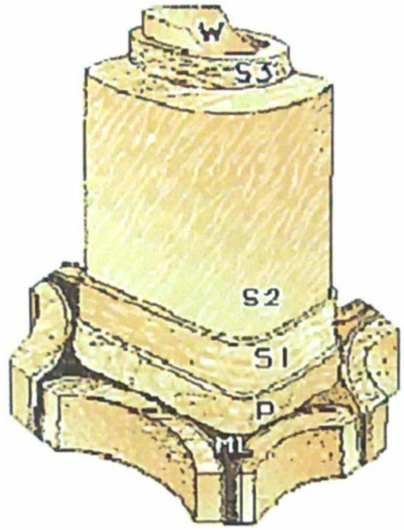

Figure 2.2. Structure of wood cell, showing the middle lamella (ML), primary wall (P), outer (S_1), middle (S_2) and inner (S) layers of secondary cell wall and the warty layer (W).

2.1.3 Chemical composition

Wood is a lignocellulosic material and is composed of approximately 50-65% cellulose, 20-25% lignin and 1-10% extractives and traces of ash. The ratio of constituents differs based on species. The absorption of water by cellulose depends on the number of hydroxyl groups that are not linked with other hydroxyl groups. Usually, the crystalline structure of cellulose will not take part in chemical reaction because of it unavailable hydroxyl groups but only the amorphous region (Fengel and Wegener, 1983).

2.2 Wood plastic composites

2.2.1 Definition

The acronym 'WPC' covers an extremely wide range of composite materials that use plastics ranging from PP to PVC and binders/fillers ranging from wood flour to natural fibers (e.g. flax) (Rails et al. 2001). WPCs are true composite materials and have properties of both wood and plastic. WPCs exhibit stiffness and strength properties between those for plastic and wood, but the density is generally higher than the individual components. The properties of WPCs come directly from their structure; they are an intimate mix of wood particles and plastic. The plastic coats the wood particle as a thin layer. The properties of WPCs can be tailored to meet the product requirements by varying the species and geometry of wood or plastic. For example, PE based products are cheaper and have a higher heat distortion temperature than the PVC based products but the PVC products are easier to paint and post treat (Anonymous, 2003). Pigments, UV stabilizers and fire retardants can all be added to the WPC raw material before extrusion to improve specific properties. WPCs have good stiffness and impact resistance properties, dimensional stability, resistance to rot, excellent thermal properties and low moisture absorption (Maldas and Kokta, 1993).

2.2.2 Applications of the WPC products

Advantages, desired properties, environmental regulations, and awareness have led to the substitution of using conventional woods with the WPC. Its production is growing over time due to its several applications (Adhikary et al. 2008). Main motives include:

- It can be molded in any particular mold with a variety of shapes and angles, so it can give any desired design (Takatani et al. 2007).
- It can be treated in the same manner as the conventional wood using the same cutting and sawing equipment (Winandy et al. 2004).

Therefore, it is easy to use any conventional wood workshop with WPC products which have proven to give the same functionality as conventional wood in many areas (Wechslera and Hiziroglu, 2009). Various WPC products are available in the US market substituting some of the conventional wood products such as outdoor deck floors (Winandy et al. 2004). It is also used for railings, fences, landscaping timbers, siding, park benches, molding and trim, window and door frames, panels and indoor furniture (Winandy et al. 2004). In addition, Wood plastic composites can also substitute neat plastics in applications where the need for an increase in stiffness is an addition; where the wood fiber elasticity is almost 40 times higher than that of polyethylene and the overall strength is approximately 20 times greater (Bengtsson and Oksman, 2006). It has also higher thermal and creep performance compared to plastics and thus could be used in many structural building applications (Wechslera and Hiziroglu, 2009).

2.2.3 Material utilized in WPC

Wood and plastics (virgin or recycled) with various types, grades, sizes, and conditions are the main materials utilized in WPC production. WPC is composed mainly from a plastic matrix reinforced with wood and other additives sometimes are added using the appropriate processing procedures. Several ingredients of WPC are found in literature. Najafi et al. 2007, mentioned that WPC is a composite composed from a natural fiber/filler (such as kenaf fiber, wood flour, hemp, sisal etc.) which is mixed with a thermoplastic. They added that virgin thermoplastic materials (e.g. high and low density polyethylene (LDPE and HDPE), polypropylene (PP), polyvinyl chloride (PVC)) are commonly utilized. In addition, any recycled plastic which can melt and be processed in a temperature less than the degradation temperature of the wood filler (200 C) could be used to produce WPC (Najafi et al. 2007). Morton and Rossi 2003, said that the huge majority of WPC utilizes polyethylene and they classified the types of plastic used in WPC as follow: polyethylene (83%), polyvinyl chloride (9%), polypropylene (7%), others (1%) (Morton and Rossi, 2003).

Clemons and Caufield added that wood flour is obtained from wood wasted from wood processors. They said also that it should be from high quality and free of bark, dirt, and other foreign matter. Moreover, species are mainly selected based on regional availability of high quality flour and color. Pine, oak, and maple are the most common used in the United States (Clemons and Caufield, 2005). Adhikary et al. 2008, used recycled and virgin high density polyethylene (HDPE) with wood flour (Pinus radiata) as filler. The HDPE utilized was obtained from a plastics recycling plant and sawdust was collected from a local sawmill (Adhikary et al. 2008).

In this study I have used polypropylene as plastic, talc as filler and karanjaoil as wood flour.

2.2.4 Manufacturing Process

The manufacturing of thermoplastic composites is usually a two-step process. The raw materials are first mixed together, and the composite blend is then formed into a product. The combination of these steps is called in-line processing, and the result is a single processing step that converts raw materials to end products. Compounding is the feeding and dispersing of the lignocellulosic component in a molten thermoplastic to produce a homogeneous material. During compounding various additives are added and moisture is removed. The compounding treatment will affect some properties of the products (Hwang and Hsiung, 2000; Hwang, 1997). Some research about the effect of different couple agents and lubricants on wood-plastic composites have also been done (Harper and Wolcott, 2004; Herrera-Franco and Valadez-Gonza´lez 2004; Lu et al. 2000). The compounded material can be immediately pressed or shaped into an end-product while still in its molten state or become a kind of small, regular pellets for future reheating and forming (Clemons, 2002). The use of compatibilisers (maleated polypropylene of different maleic anhydride content) in the compounding step improved the mechanical properties of the composites in dry conditions regardless of the compounding process; however, in wet conditions a decrease in tensile and flexural strength was observed for all composites (Bledzki et al. 2005).

Three common forming methods for WPC are extrusion (forcing molten composite through a die), injection molding (forcing molten composite into a cold mold), and compression molding (pressing molten composite between mold halves) Extrusion is by far the most common method (Clemons, 2002), the total poundage of products produced with injection and compression is much less than that is produced with extrusion (English et al. 1996).

2.2.5 Advantage of WPC Over Other Materials

The fact that WPC ingredients are mainly composed from wood and plastic has led to the rapid worldwide growth of its production due to the high availability of non-utilized plastic and wood wastes. Dividing the subject into two main sub-subjects, the plastic waste has the highest contribution regarding its huge available quantities which gives a strong advantage to WPC. The market potential regarding the usage of plastic waste into other utilizations is huge due to the high amounts of its disposition which constitutes the largest share of the global municipal and industrial solid waste. Kikuchi et al. 2008, mentioned that the plastic waste constitutes more than 60% of the total MSW, 22% was recovered and 78% disposed (Kikuchi et al. 2008). In United States, the waste of plastics; in 2005, was calculated as 11.8% of the 246 million tons of MSW generated (USEPA 2006). In India, Plastic in municipal solid waste makes up to 9–12% by weight of the total in addition to other wastes which may contain much higher proportions of plastics (Panda et al. 2010). The majority of the plastic wastes generated are disposed (Kikuchi et al. 2008). However, the continuous growth of worldwide plastic consumption due to its short life cycle compared to other products; roughly 40% have duration of life cycle smaller than 1 month, and the legislations of many countries concerned with minimizing landfills content and incinerators have led to a necessity of recovering plastic waste instead of disposing (Kikuchi et al. 2008) & (Panda et al. 2010). Incineration and land filling alternatives were rejected by several countries due to their potential danger to the environment either by polluting air or land; which results in not closing the loop of Cradle to Cradle and therefore depleting natural resources. As a consequence, the tendency towards recycling has increased (Jayaraman and Bhattacharyya, 2004). Some attempts for plastic recovery resulted during 2004 in a recovery of almost 8.25 million tons (39% of total amount of plastics consumed) in Western Europe; 35,000 tons (13.48% of total imported virgin plastics) in New Zealand (Adhikary et al. 2008). While in 2005, the United States recycled around 5.7% of the total plastics generated (USEPA 2006). On the other hand, some states in the US like Michigan have a recycling rate that is close to 100% (Beg and Pickering, 2008). In Brazil, some potential in recycling have been raised where around 15% of all plastics consumed are recycled and returned to industry (Beg and Pickering, 2008).

Therefore, the tendency towards recycling plastic instead of other options made it better for the sake of WPC production increase in the future. On the other hand, wood waste has a significant contribution to the total amount of waste especially that it comes from various commercial, industrial, and residential activities; which could include scrap lumbers, pallets, sawdust, tree stumps, branches, twigs, wooden crates and pallets, building construction and demolition, furniture manufacturing, and many others. In addition, it is one of the main environmental concerns stated by many countries. In the United States, a report that was written in 1995 by CIWMB (California Integrated Waste Management Board) tells that severe problems concerned with landfill disposing were revealed (CIWMB 1995). It tells that the construction and demolition of buildings; which are mainly wood waste, generates almost twelve percent of all solid waste in California. Furthermore, the average fee for disposing of a ton of waste in a California landfill is about $30 to $35, but disposing of a ton of wood at a wood processing facility may only cost $10. In addition, the amount of wasted wood disposed in landfills in some regions in California reaches 90 percent of the total wood waste (CIWMB 1995). Adhikary et al. 2008, stated that a large amount of wood waste is generated from wood industry at different stages of the processing of wood; which is disposed mostly in landfills; Besides, the hazardous content of the wood waste are numerous and takes time to decompose (Adhikary et al. 2008). The Department of Environmental Quality (DEQ) in the United States reported that the other alternative; that used to be used, to get rid of wood wastes instead of disposing was burning (DEQ 2009). Wood burners were used at first and as a result of their environmental hazards; represented in huge amount of smoke & ash generated directly to the atmosphere polluting air and ambient, were shut down and prohibited from being used (DEQ 2009). Currently, a tremendous shift is done in the area of wood burning especially with the developed ideas of avoiding the environmental hazards. Therefore, the use of wood waste in WPC helps to overcome disposal and burning hazards and costs (Adhikary et al. 2008).

WPCs aim to increase the efficiency of wood usage by up to 40% compared to traditional wood processing. WPCs also provide other environmental benefits, such as:

- They use residual wood (eg. sawdust) and recycled plastic.
- WPCs contain no formaldehyde or volatile organic compounds.
- WPCs are potentially recyclable since it can be reground and processed.
- WPCs are considered nonhazardous waste and can be disposed of by standard methods. The basic material structure of WPCs shows that leaching from WPCs is minimal to non-existent (Anonymous, 2003).

2.2.6 Market potential

The awaiting market for WPC is huge due to the high production of plastics and wood which constitutes a significant amount of solid waste which is mostly disposed not recovered (Adhikary et al. 2008). Najafi et al. 2007, mentioned that WPC presents a promising raw material source for new value added products due to the large amount of daily waste generation and low cost (Najafi et al. 2007). WPC commercial products are increasingly replacing many products in many applications especially the construction related ones (Yeh et al. 2009). WPCs have gained an ever larger share; especially for decks and other outdoor structures (Youngquist et al. 1992). Other production lines of fencing, roofing, and siding have started to get a noticeable market share (Winandy et al. 2004). WPC usage is extensively spread especially in strips; where wood peel layers are tilted in the same direction, used in furniture industry (Augutis, 2004). WPC is also used in producing panels where it is produced by mixing wood flour and plastics giving a material which can be processed similar to 100% plastic-based products (Wechsler and Hiziroglu, 2007). Approximately one-half of all industrial materials used in the United States are wood-based; thus, the finding that the WPC market is increasing is not a surprise (Falk, 1997). The growth of WPC decking in the U.S. has started from less than 1 % in mid-90's to over 10% today with growth projected by several studies to reach 20% before the end of 2010 (Winandy et al. 2004). Two large sectors, the decking and fencing sector, the siding and roofing sector started to use the WPCs commercially in the U.S. (Winandy et al. 2004). Concerning the decking and fencing in the U.S., a study was done in 2002 which showed that there were 1.4 million new houses constructed (for single families) and 0.3 million new houses for multi-families; where the house averaged about 215 m^2 made from wooden decks (Winandy et al. 2004). Winandy et al. 2004, concluded that all this huge amount of consumed wood could be substituted by WPC. The U.S. decking market alone uses a sum total of nearly 18.5 million m^3 of wood where 90% uses natural treated wood and 10% WPC (Winandy et al. 2004). In addition, the U.S. fencing market was divided into 45% wood, 44% metal, 7% plastic and 5% other material (Winandy et al. 2004). It was calculated at $US 2.6 billion in 2002 and was expected to grow approximately 5% per year and therefore a great potential of WPC domination was expected (Winandy et al. 2004).

2.2.7. Current status of WPC production

Although the WPC industry is still only a fraction of a percent of the total wood products industry, it has made significant inroads in certain markets. According to estimates, the WPC market was 320,000 MT in 2001 and the volume is expected to more than double by 2005. (www.plastemart.com).

2.3 Response Surface Methodology

RSM is a collection of mathematical and statistical techniques useful for developing, improving and optimizing processes and can be used to evaluate the relative significance of several affecting factors even in the presence of complex interactions. The main objective of RSM is to determine the optimum operational conditions for the system or to determine a region that satisfies the operating specifications. The application of statistical experimental design techniques in adsorption process development can result in improved product yields, reduced process variability, closer confirmation of the output response to nominal and target requirements and reduced development time and overall costs.

Objectives of RSM are the following:

- √ To generate knowledge in the experimental domain of interest.
- √ To reliably estimate the experimental variability (pure error).
- √ To guarantee the adequacy between the proposed model and the experimental data (to make it easy to detect the lack of fit).
- √ To predict the observed response, as exactly and precisely as possible, in points within the experimental domain where no experiments were done.
- √ To propose sequential strategies to carry out the experimentation with different alternatives according to the results obtained.
- √ To maintain a high efficiency with respect to economical cost, time, and any other practical limitations.
- √ To make the identification of outlier data easy.
- √ To make the decision making possible under uncertainty conditions, reducing the ambiguity.

Theoretical Model

The relation between variables and response is theoretically described by a function that is the underlying physical mechanism to the problem under study. The existence of this relation makes the phenomenon under study sufficiently reproducible to be able to experiment with it and to extract conclusions:

$$y = f(U_1, U_2, \ldots, U_k) + \varepsilon \quad (1)$$

In Equation (1), ε represents other sources of variability that were not considered in f like the error in the determination of the response.

ε is a random variable supposed to follow a normal distribution with a mean of zero and a variance of σ^2. As the mean value is zero, the expected value $E(y)$ of the experimental response is precisely the function f:

$$E(y) = \eta = E\left[f(U_1, U_2, \ldots, U_k)\right] + E(\varepsilon) \quad (2)$$

$$\eta = f(U_1, U_2, \ldots, U_k)$$

2.4 Box-Behnken Design

Box–Behnken design (BBD) is an independent, rotatable quadratic design with no embedded factorial or fractional factorial points where the variable combinations are at the midpoints of the edges of the variable space and at the center (Prakash Maran, Sivakumar, Sridhar, & Prince Immanuel, 2013). The application of statistical experimental design techniques in bioprocess development and optimization can result in enhanced product yields, closer conformance of the process output or response to target requirements and reduced process variability, development time and cost. On single factor analysis, independent variables and their ranges were selected. Experiments were established based on a BBD with three factors at three levels and each independent variable were coded at three levels between −1, 0 and +1. The coding of the variables was done by the following equation (Prakash Maran & Manikandan, 2012) :

$$X_i = \frac{Xi - Xz}{\Delta Xi} \qquad i = 1,2,3,\ldots,k$$

Where Xi, is the dimensionless value of an independent variable; Xi is the real value of an independent variable; Xz is the real value of an independent variable at the center point; and Xi is the step change of the real value of the variable i corresponding to a variation of a unit for the dimensionless value of the variable i.

Box-Behnken designs (BBD) are a class of rotatable or nearly rotatable second-order designs based on three-level incomplete factorial designs. For three factors its graphical representation can be seen in two forms: 1a. A cube that consists of the central point and the middle points of the edges, as can be observed in Fig. 1a.

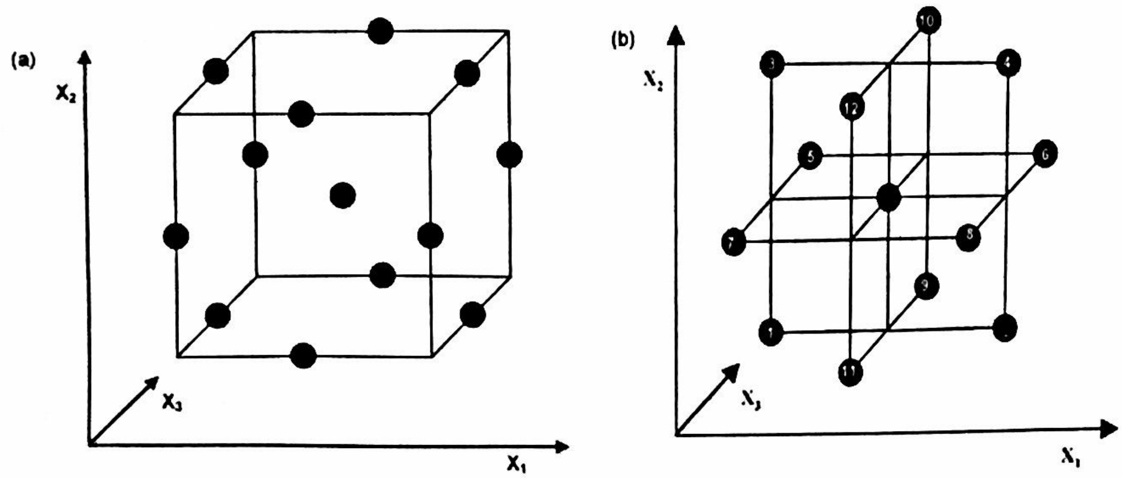

Fig. 1. (a) the cube for BBD and three interlocking 2^2 factorial design (b).

2.5 Desirability Function

The desirability function approach is a popular and established technique for the simultaneous determination of optimum settings of input variables that can determine optimum performance levels for one or more responses. Harrington (1965) first developed the desirability function, and it was later modified by Derringer and Suich (1980) for specifying the relationship between predicted responses on a dependent variable and the desirability of the responses. The desirability procedure involves two steps: (1) finding the levels of the independent variables that simultaneously produce the most desirable predicted responses on the dependent variables and (2) maximize the overall desirability with respect to the controllable factors. Therefore, the desirability functions are used in order to obtain qualitative and quantitative responses by the simple and quick transformation of different responses to one measurement. The general approach of desirability function is to first convert the response into an individual desirability function (d_i) that varies from 0 to 1 (lowest desirability to highest desirability).

The individual desirability scores for the predicted values for each dependent variable are then combined into overall desirability function, D, by computing their geometric mean of different d_i values.

$$\mathbf{D=(d_1 \times d_2 \times d_3 \times \cdots \times dn)^{1/n}}$$

where d_i indicate the desirability of the response and n is the number of responses in the measure. If any of the responses beyond the desirability, then overall function turned into zero.

It can be extended to

$$D = [d_1^{\alpha 1} \times d_2^{\alpha 2} \times \cdots \times d_n^{1/n}]^{1/n}, \quad 0 \le \alpha_i \le 1 \quad (i = 1, 2, 3, \ldots, n),$$

$$\alpha_1 + \alpha_2 + \cdots + \alpha_n = 1$$

where d_i indicates the desirability of the different responses Y_i ($i = 1, 2, 3, \ldots, n$) and α_i represents the importance of responses. So, maximum over all desirability function D depends on the α_i (importance) value.

Depending on whether a particular response Y_i is to be maximized, minimized or assigned a target value, the different desirability functions d_i (Y_i) used are those proposed by Derringer and Suich (1980). Let L_i, U_i and T_i be the lower, upper and target values, respectively, that are desired for response Y_i, with $L_i \le Y_i \le U_i$. If a response is of the "target is the best" kind, then its individual desirability function is:

$$d_i = \left(\frac{Y_i - L_i}{T_i - L_i}\right)^p \quad \text{if } L_i \le Y_i \le T_i$$

$$d_i = \left(\frac{Y_i - U_i}{T_i - U_i}\right)^q \quad \text{if } L_i \le Y_i \le T_i$$

$$d_i = 1 \quad \text{if } Y_i = T_i$$

$$d_i = 0 \quad \text{if } Y_i \le L_i \text{ or } Y_i = L_i$$

with the exponents p and q determining how important it is to hit the target value.

If a response is to be maximized instead, the individual desirability is defined as shown in Eq.

$$d_i = 0 \quad \text{if } Y_i \le L_i$$

$$d_i = \left(\frac{Y_i - L_i}{T_i - L_i}\right)^p \quad \text{if } L_i \le Y_i \le T_i$$

$$d_i = 1 \quad \text{if } Y_i \ge T_i$$

Finally, if a response is to be minimized, the individual desirability (d_i) is calculated according to Eq.

$$d_i = 1 \quad \text{if } Y_i \le T_i$$

$$d_i = \left(\frac{Y_i - U_i}{T_i - U_i}\right)^q \quad \text{if } T_i \le Y_i \le U_i$$

$$d_i = 0 \quad \text{if } Y_i \ge U_i$$

2.6 General Description of Karanja (*Pongamia pinnata* L.)

Pongamia pinnata (L.) is a medium sized glabrous tree popularly known as Karanja in Bengali and Hindi, Indian beech in English and Pongam in Tamil. It's botanical name is *Pongamia pinnata* (L.) Pierre. It is adaptable tree for tropical and sub-tropical regions which requires excellent drainage and a sunny location. It grows easily from seed. Historically, this plant has long been used in India and neighboring regions as a source of traditional medicines, animal fodder, green manure, timber, fish poison and fuel. Extract of the plant possess significant anti-di arrhoeal, anti-fungal, anti-plasmodial, anti-ulcerogenic, anti-inflammatory and an algesic activities. Its oil is a source of biodiesel (Meher et al. 2006). It has also alternative source of energy, which is renewable, safe and non-pollutant.

Pongamia pinnata (L.) belongs to family Leguminosae and sub-family Papilionaceae (Merra et al. 2003). It is a medium sized glabrous, perennial tree grows in the littoral regions of South Eastern Asia and Australia (Satyavati et al. 1987; Allen and Allen, 1981). *Pongamia pinnata* is a preferred species for controlling soil erosion and binding sand dunes because of its dense network of lateral roots. Karanja is the native species for Bangladesh, India, Myanmar, Nepal, Thailand and also exotic species for Australia, China, Egypt, Fiji, Indonesia, Japan, Malaysia, Mauritius, New Zeeland, Pakistan, Philippines, Seychelles, Solomon Islands, Sri Lanka, Sudan, United States of America (Orwa et al. 2009). Native to humid and subtropical environments, pongam thrives in areas having an annual rainfall ranging from 500 to 2500 mm. in its natural habitat, the maximum temperature ranges from 27 to 38°C and the minimum 1 to16°C.

The wood is yellowish grey in colour, heavy, moderately strong, moderately tough, hard, medium course textured and interlocked grained. It is not durable, liable to split and warp but seasons well with care and fairly easy to work, turn and finish. The wood is used for construction, tool handles, turnery articles and agricultural implements. According to Allen and Allen (1981) the *Pongamia pinnata* is a fast-growing tree which reaches 40 feet in height and spread, forming a broad, spreading canopy casting moderate shade.

3. Materials and Methods

3.1 Collection and Preparation of Sample

Karanja tree is collected from Dumuria Upozilla under Khulna District as raw material for the manufacturing of Wood Plastic Composite board. For the purpose of preparing samples the defect free bole is selected and then it chipped by chopper machine. After chipping, the wood chips are run into grinder machine, by which the wood turned into Wood Flour. In this study the size of wood flour ranges < 1mm is used. The PP granules are then processed by grinder to pass through a mesh screen. Finally talc is collected from cosmetic market, which is available as raw material.

3.2 Selecting Variables

There are two types of variables, i.e. dependent and independent. In this study, temperature and pressure are the dependent variable. Temperature is fixed at 180°c and pressure is 4 mpa. According to Jan Benthien & Heiko Thoemen, (2012) temperature has little effect on mechanical properties of WPC board. Different study shows that 4 mpa pressures are better for producing good quality WPC board. On the other hand, melting temperature of polypropylene is ranges 130-160°C. So that fixing temperature at 180°C is very reasonable for this study.

Beside this, wood-plastic ratio, talc percentage and pressing time are the independent variables. Wood and plastic are quite difference in their nature, i.e. wood is hydrophilic and plastic is hydrophobic. A lot of study proved that wood-plastic ratio combination has a great effect on WPC board. Nadir A. et al., (2011) say that time condition has a vital impact on mechanical and physical properties also. Now a day, talc is extensively used in plastic and rubber industries (Iarc Monographs, Volume-93). Ross et al., (1968); Rayner & Brown, (1973) demonstrated that talc is triclinic in structure which increases the bonding capacity of plastic as well as polypropylene.

3.3 Experimental Design

Box–Behnken design (BBD) is an independent, rotatable quadratic design with no embedded factorial or fractional factorial points where the variable combinations are at the midpoints of the edges of the variable space and at the center. In the present study, by employing the Box–Behnken statistical experiment design and the RSM, the effects of the three independent variables (wood-plastic ratio, talc percentage and pressing time) is investigated and to determine the optimal conditions were determined to maximize the percent yield of WPC board. Experiments were established based on a BBD with three factors at three levels and each independent variable were coded at three levels between −1, 0 and +1. The great advantage of Box–Behnken design is that it avoids extreme treatment combination. The applied Box-Behnken is consisted of 15 experiments only.

Table 1. DESIGN SUMMARY: 3 factor Box-Behnken design

Factors				Range and label	
			Low(-1)	Middle(0)	High(+)
Ratio=Wood flour :PP*			**1 =70:30**	**2 = 60:40**	**3 = 50:50**
Talc			**0**	**5**	**10**
Pressing time (minute)			**8**	**10**	**12**
Run	**Wood flour :PP**	**Talc**	**Pressing time**	**MOR**	**MOE**
1(C)	2.00	5.00	10.00		
2	3.00	10.00	10.00		
3	1.00	10.00	10.00		
4	3.00	5.00	8.00		
5	3.00	5.00	12.00		
6	2.00	0.00	8.00		
7	1.00	0.00	10.00		
8	2.00	0.00	12.00		
9	2.00	10.00	8.00		
10(C)	2.00	5.00	10.00		
11	3.00	0.00	10.00		
12	2.00	10.00	12.00		
13(C)	2.00	5.00	10.00		
14	1.00	5.00	8.00		
15	1.00	5.00	12.00		

Note :(C) indicates center points run and PP indicates polypropylene

3.4 Determination of Mechanical Properties

All the samples are cut into required dimension for testing mechanical properties. The laboratory test for characterization of mechanical properties is carried out in the laboratory of Civil Engineering Department of Khulna University of Engineering and Technology, Khulna, Bangladesh.

3.4.1 Modulus of Rupture (MOR)

Modulus of Rupture (MOR) is measured by the University Testing Machine (UTM), Model no: UTM-100, maximum capacity-100000 kgf. MOR was calculated by the following formula-

$$\text{MOR} = \frac{3pl}{2bd^2} \quad \text{.....................} \quad (1)$$

3.4.2 Modulus of Elasticity (MOE)

Modulus of Elasticity (MOE) is measured by the University Testing Machine (UTM), Model no: UTM-100, maximum capacity-100000 kgf. MOE is calculated by the following formula-

$$\text{MOE} = \frac{pl^3}{4\Delta bd^3} \text{ .... (2)}$$

Where, p = load in N, l = span length in mm, b = width of the test specimen in mm, d = thickness of test specimen in mm and Δ = deformation of the board in mm.

3.5 Determination of Physical Properties

All the samples are cut into (5cm × 5cm) dimension for testing physical properties. The laboratory test for characterization of physical properties is carried out in the laboratory of Forestry and Wood Technology Discipline, Khulna University, Bangladesh. At first all the specimens are weighted and green dimension are taken at room temperature. Then all the samples are kept into oven for 24 hours. After drying oven dry weight and dry dimension are also measured. Next, the samples are soaked into water for 120 hour. Finally, the wet dimension are taken and all the physical properties are calculated by using following formula-

$$Density = \frac{Weight\ of\ Wood}{Standard\ Volume}$$

$$Moisture\ Content = \frac{Green\ Weight - Oven\ Dry\ Weight}{Oven\ Dry\ Weight} \times 100$$

$$Shrinkage = \frac{Green\ Dimension - Dry\ Dimension}{Green\ Dimension} \times 100$$

$$Swelling = \frac{Wet\ Dimension - dry\ Dimension}{Dry\ Dimension} \times 100$$

3.6 Data and Statistical Analysis

The data were collected and analyzed by Excel 2007 and Box-Behnken design software was used as a RSM to evaluate the broader effect of the significant factors. STATISTICA® software was used for the design of experiment. A second order polynomial model used to fit the response to the independent variables is shown below –

$$Y = \beta_0 + \sum \beta_i X_i + \sum \beta_{ii} X_i^2 + \sum \beta_{ij} X_i X_j \quad \text{.......................(1)}$$

Where Y is the response (MOR), β_0 is the intercept and β_i, β_{ii}, β_{ij} are the coefficient of parameters for liner, squared and interaction effects respectively.

4.1 Mechanical Properties

4.1.1 Sufficiency of the Design

Main manufacturing process parameters are wood plastic ratio, talc percentage and pressing time. According to the experimental design with three processing variables each having three levels of variable, RSM design yielded a total of 15 runs in a random order. Physical and mechanical properties of the board are significantly affected by the processing parameters. In this study Box-Behnken design is used to evaluate the combination effect of different parameters on the board quality like MOR and MOE. So it is needed to adequacy of the design which is evaluated through Analysis of Variance (ANOVA) and observed vs. predicted plot for MOR and MOE.

ANOVA for MOR and MOE showing below in table -1 and table -2 respectively. Lack of fit (LOF) test that allows us to determine if the current model adequately accounts for the relationship between the response variable and the predictors or not. So lack of fit (LOF) test is conducted in ANOVA. It is a special investigative test for adequacy of a model fit, hence the effects of additional higher order term are removed from the error. If the model does not fit the data well, this will be significant. Three central points are used for calculating the pure error. In this study the value of LOF is not significant relative to the pure error regarding to MOR and MOE, which indicates a good response to the model.

From the ANOVA table co-efficient of determination (R^2) value is 0.96 for MOR and also 0.96 for MOE is highly agreement with the experimental results, indicating 96% of the variability can be revealed by the model and are left with 4% both of residual variability for MOR and MOE. For further soundness of the model, adjusted R^2 is used for confirming the model adequacy. The adjusted R^2 is calculated to 0.896 and 0.888 for MOR and MOE, which marked a good model for application in the field conditions.

Table 2. ANOVA for Response Surface Quadratic Model for MOR

Source	Sum of Squares	df	Mean Square	F- Value	Prob > F	Remarks
(1)Ratio(L)	224.3756	1	224.3756	670.7123	0.001488	Significant
Ratio(Q)	19.9074	1	19.9074	59.5080	0.016392	Significant
(2)Talc(L)	35.7329	1	35.7329	106.8143	0.009233	Significant
Talc(Q)	16.7598	1	16.7598	50.0991	0.019382	Significant
(3)Pressing Time(L)	1.7531	1	1.7531	5.2405	0.149249	
Pressing Time(Q)	0.0874	1	0.0874	0.2613	0.660091	
1L by 2L	24.0468	1	24.0468	71.8815	0.013628	Significant
1L by 3L	39.6270	1	39.6270	118.4546	0.008337	Significant
2L by 3L	1.9044	1	1.9044	5.6927	0.139760	
Lack of Fit	13.4919	3	4.4973	13.4435	0.070027	In-Significant
Pure Error	0.6691	2	0.3345			
Total SS	381.3866	14				
R^2=0.9628; Adjusted R^2=0.8960; L indicated linear effect; Q indicated quadratic effect						

Table 3. ANOVA for Response Surface Quadratic Model for MOE

Source	Sum of Squares	df	Mean Square	F- Value	Prob > F	Remarks
(1)Ratio(L)	243956.4	1	243956.4	98.63368	0.009987	Significant
Ratio(Q)	4261.4	1	4261.4	1.72293	0.319714	
(2)Talc(L)	132917.8	1	132917.8	53.73983	0.018104	Significant
Talc(Q)	222232.6	1	222232.6	89.85055	0.010947	Significant
(3)Pressing Time(L)	40224.4	1	40224.4	16.26308	0.056343	
Pressing Time(Q)	9807.9	1	9807.9	3.96540	0.184688	
1L by 2L	64232.5	1	64232.5	25.96974	0.036416	Significant
1L by 3L	19493.7	1	19493.7	7.88149	0.106915	
2L by 3L	3829.1	1	3829.1	1.54815	0.339450	
Lack of Fit	25893.3	3	8631.1	3.48963	0.230676	In-Significant
Pure Error	4946.7	2	2473.4			
Total SS	773056.7	14				
R^2=0.9601; Adjusted R^2=0.8883; L indicated linear effect; Q indicated quadratic effect						

As well as LOF test, the model is again evaluated by observed vs. predicted plot. The graphical presentation shows that the points all predicted and actual responses (Figure – 1 & 2) are pointed along with 45° straight line which signify another good reply of the model.

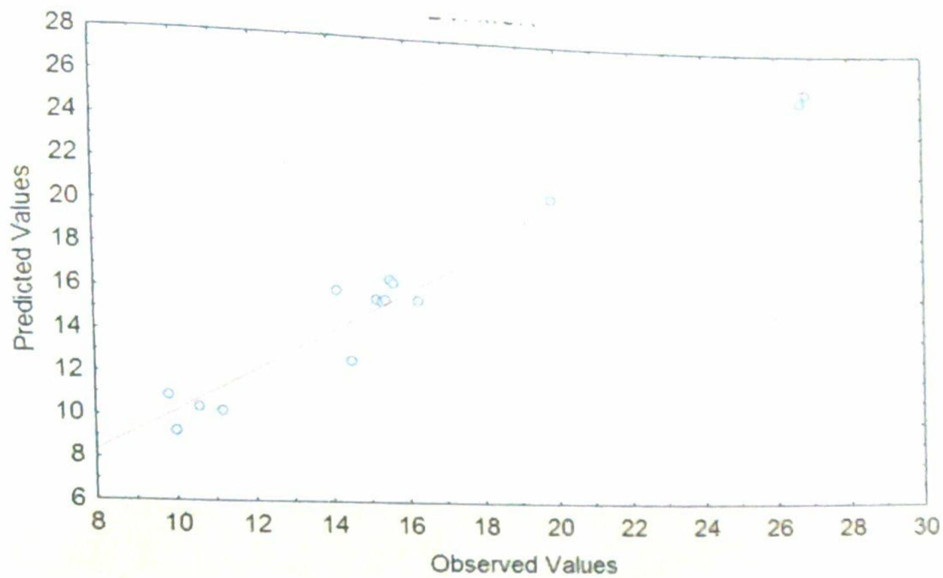

Figure-1: Observed vs. Predicted plot for MOR.

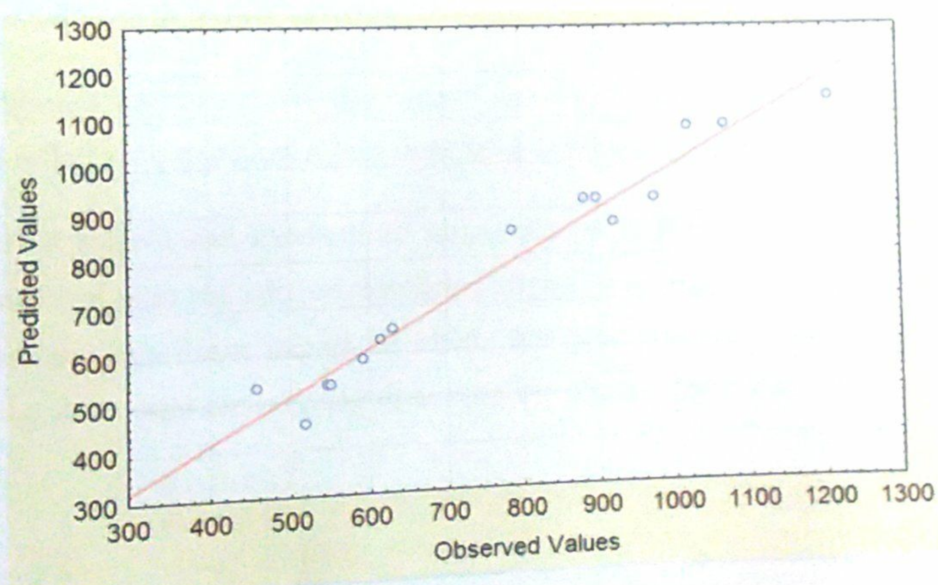

Figure-2: Observed vs. Predicted plot for MOE.

From the above statistical results, it may arrive at a judgment by reasoning that the Box–Behnken design is sufficient to predict the board strength (MOR and MOE) within the range of variables studied. The final predicted mathematical model in terms of actual significant factors for wood plastic composite board production control by different parameters are given below –

$$MOR = -17.10333 + 14.19833 * Ratio + 0.72058 * Talc + 2.26604 * Pressing\ time - 0.49050 * Ratio * Talc - 1.57375 * Ratio * Pressing\ time + 0.069000 * Talc * Pressing\ time + 2.32167 * Ratio^2 - 0.085233 * Talc^2 + 0.038542 * Pressing\ time^2$$

$$MOE = +254.36667 - 183.59167 * Ratio + 92.10183 * Talc + 136.95792 * Pressing\ time - 25.34400 * Ratio * Talc + 34.90500 * Ratio * Pressing\ time + 3.09400 * Talc * Pressing\ time + 33.97167 * Ratio^2 - 9.81333 * Talc^2 - 12.88458 * Pressing\ time^2$$

4.1.2 Factors affecting MOR

It has been observed from ANOVA (table – 1) and standardized pareto chart for MOR that the actual factors have significant effect on MOR of wood plastic board which is unfolded by the software depicted in **Figure- 3**.

From the figure-3 we have observed a vertical line which overpass through the standardized factors and reflects the statistical significance level at 95% confidence intervals.

From ANOVA **table-1** and standardized parteo chart of **figure-3,** it has been observed that the linear effect of ratio and talc has significant impact on MOR. Quadratic effect of ratio and talc has also the significant impact on MOR. It's again observed that the positive linear interaction between ratio and pressing time, ratio and talc has significant impact on MOR.

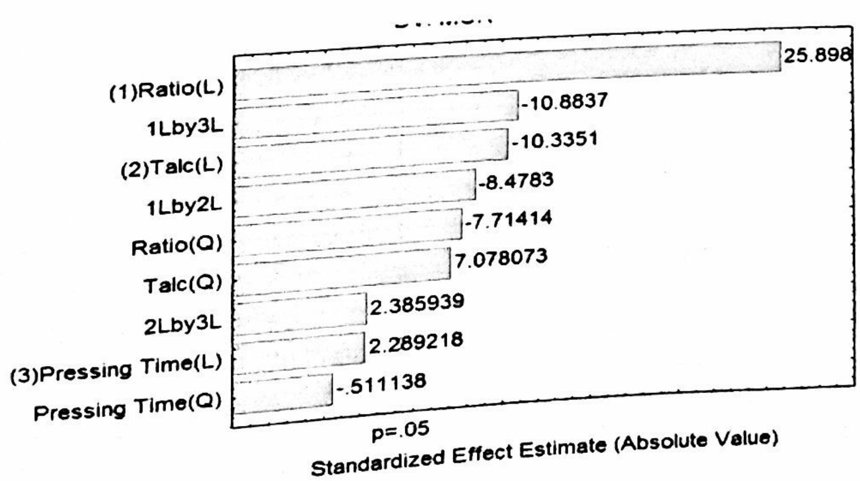

Figure- 3 : Standardized pareto chart for MOR

It has been remarked from the Fig. 4 that the MOR of wood plastic board arrived at the highest value 26.88 N/mm^2 for low pressing time ranges 9 to 10 minutes and high ratio of 3. As the pressing time start to increase from 10 to 12 minute the MOR start to decrease sharply. Nadir A. et al. 2011 described in their investigation that MOR decreases with the increase of treatment time for wood plastic composite board. This strength (MOR) loss in wood is actually related to the progressive degradation of hemi-cellulose components due to increasing pressing time after a certain period of time. Loss in MOR of wood-based panels (Ayrilmis et al. and Ohlmeyer et al. 2004) treated at high temperatures was reported by different authors. Similar results were also found the WPC panels in the present study.

On the other hand, as the ratio increases MOR of the boards are also increases. The highest strength of WPCs were measured when the lowest wood content is used and the strength decreased most severely when wood content increases (Shao-Yuan et al. 2011).

From the standardized pareto chart (Fig. 3) a negative interaction effect exists between pressing time and ratio which depicted in (Fig. 4). The following figure Illustrated that high MOR values obtained when the pressing time ranges between 9 to 10 for high ratio ranges 3. The Fig. 4 also demonstrated that the MOR start to decrease with the increase of pressing time. It's again indicated that the combination of high pressing time and low ratio has detrimental effect on MOR.

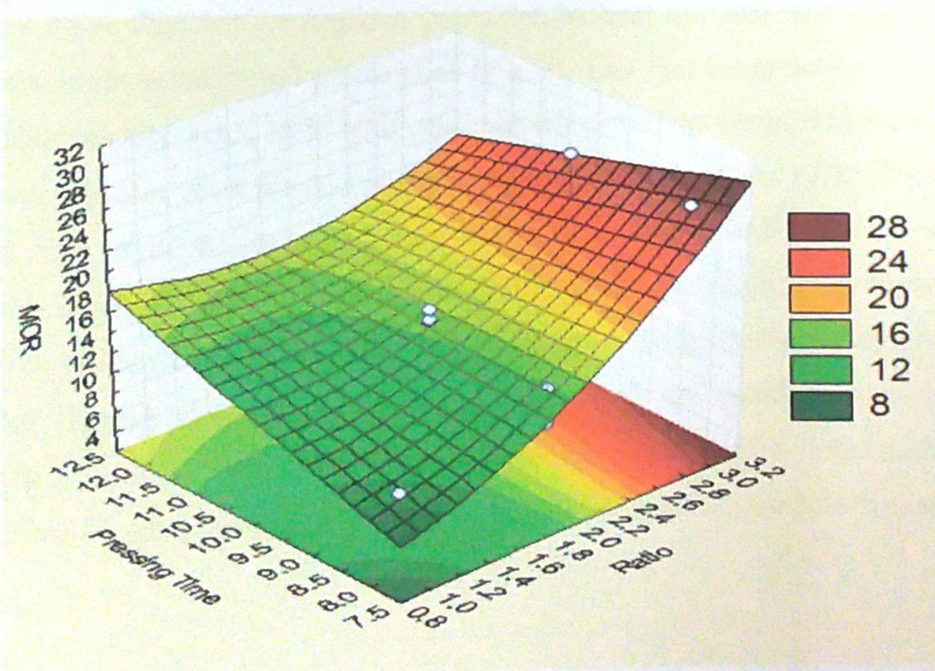

Figure 4 : 3d graph showing the effect of pressing time and ratio on MOR.

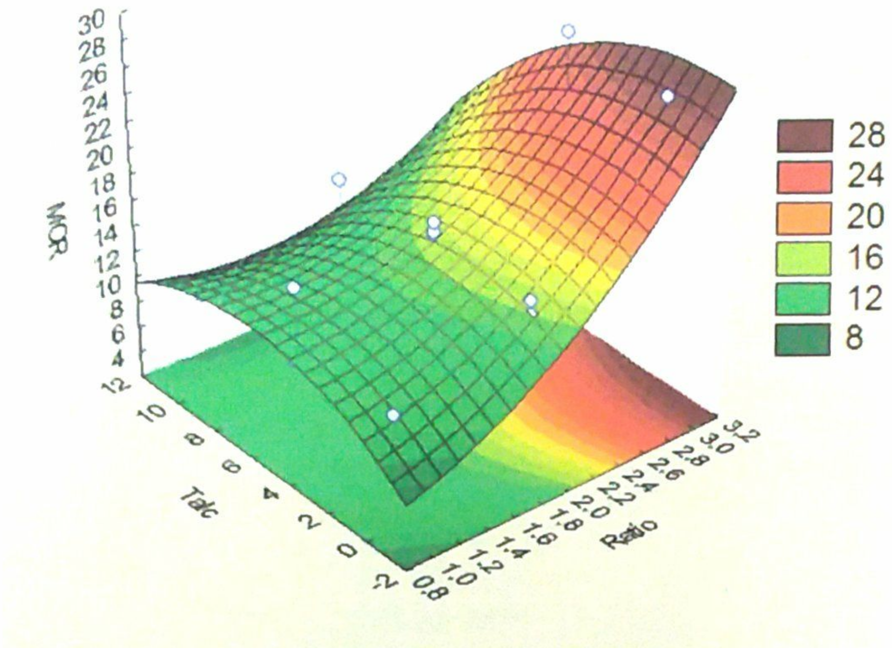

Figure- 5 : 3d graph showing the effect of talc and ratio on MOR

The above figure depicted the negative interaction between talc and ratio which also have been shown in the standardized pareto chart (Fig. 3). This figure also demonstrated that the MOR is obtained high value 26.88 N/m^2 when the talc percentage ranges 2 to 4 and high ratio of 3. It also seen that when the talc percentage is increasing from 3 to 10, it affect the MOR decreases. Talc improved chemical bond between the hydrophobic PP polymer chains and hydrophilic cellulosic fibers (www.luzenac.com.). Talc has significantly higher thermal conductivity (compared to the polymer), heat introduced and generated during processing is transmitted through the mixture more quickly. Which are again responsible for the degradation of hemi-cellulose components as well as decreasing MOR. Similar observations were reported for other lignocellulosic fibers based PP composites (Kauppinen et al. 1997).

4.1.3 Factors affecting MOE

Different processing parameters and their interaction are presented by Standardized Pareto chart (Fig. 6) for selected response of MOE. This chart represent the statistical significance at 95% confidence intervals and also reflects Positive coefficients which indicate the MOE is suitable and negative coefficients indicate unsuitable by the parameters and their interactions.

Within this study, we have observed from ANOVA (Table- 2) for MOE and standardized pareto chart (fig. 6) that the linear effect of ratio and talc, the quadratic effect of talc has significant impact on the MOE. It has been also showed that the linear interaction effect between ratio and talc (i.e. 1L by 2L) has the most significant impact on MOE.

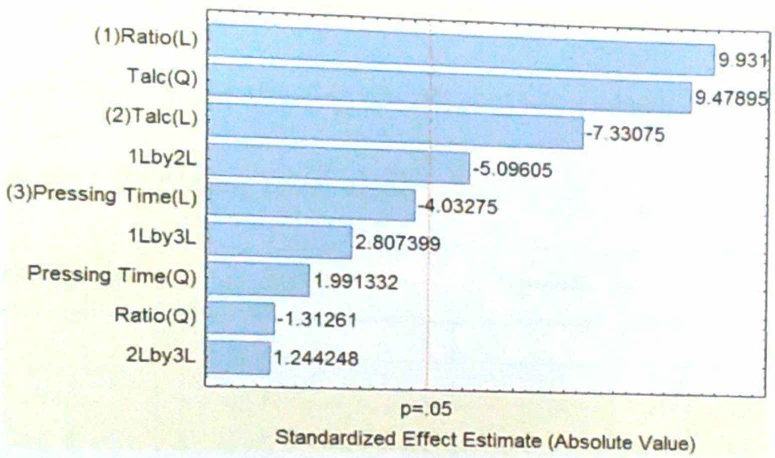

Figure- 6 : Standardized pareto chart for MOE

From the Fig. 4, it has been attributed that the combination effect of lowest talc content and highest ratio produced wood composite board with high MOE. It has also been observed that the MOE of wood composite board attained the highest value 1210.01 N/mm^2 for lowest talc content ranges 2 to 3 percentage and high wood plastic ratio of 3. According to Stark, N.M. et al., 2003 one of the primary reasons to add filler is to develop good bonding between wood–plastic and also improve the stiffness and strength of the board. In this regard we have seen within this study that using of talc as filler increases MOE. But earlier discussed that high quantity of talc increases thermal effect which may degraded the inner lignocellulosic component as well as MOE (Kauppinen et al. 1997).

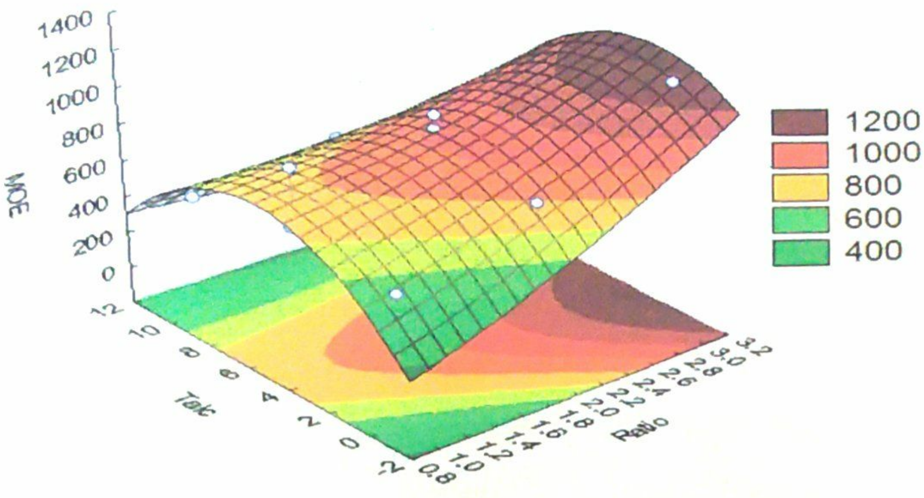

Figure- 7 : 3d graph showing the effect of talc and ratio on MOE

4.1.4 Optimization By Using Desirability Function

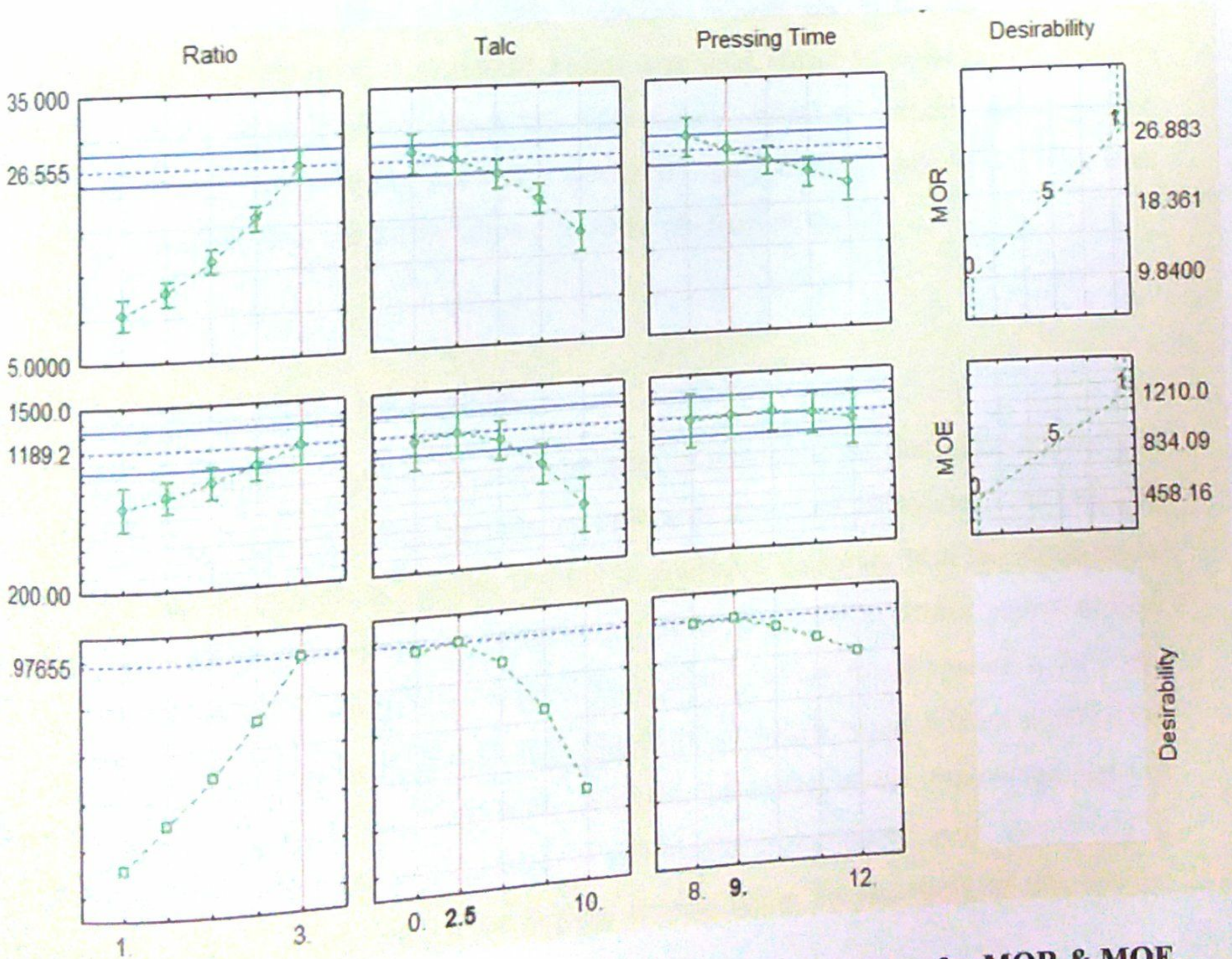

Figure-8 : Desirability profile for optimization of process parameters for MOR & MOE.

The multiresponse optimization process is done by selecting software profile and desirability option. Earlier in this paper chapter two (2.5) the approaches of desirability function is summarized. In this study the response MOR and MOE is optimized by this desirability function. Above desirability function consist a series of graph shows a prediction profile for a dependent parameters. The best optimized condition are found to be pressing time 9 minutes, talc percentage 2.5 and WF/PP ratio 3. This function also optimized that the MOR is 26.88N/mm^2 and MOE is 1210N/mm^2. After this optimization process of each factor, predicted value is used to perform a confirmation study. From the confirmation study the MOR and MOE value is obtained 28.89 N/mm^2 and 1223.92 N/mm^2 respectively. Which is closely related with the data obtained from desirability optimization by using Box–Behnken design.

4.2 Physical Properties

In this study, there are three processing variables. Which are wood-plastic ratio, talc percentage and pressing time. A statistical design is applied, where 15 experimental board is manufactured. Some of physical properties like density, moisture content, shrinkage and swelling are measured for every individual board. By the statistical analysis we have seen that all the variables have the hardly impact on these physical properties.

4.2.1 Factors Affecting on Density

Density is quantity that is used to describe the mass of a material per unit volume (Irle and Barbu, 2010). From the following figure-9, we have seen that wood plastic ratio and pressing time has the similar impact on density. Density is gradually decreases with the increases of pressing time and plastic content in wood-plastic ratio. But after a certain period density curve again rises. Highest density is obtained 1.01gm/cm^3, where wood content is 70% and pressing time is 8 min. Lowest density is 0.78gm/cm^3 in which wood content is 60% and pressing time is 10 min. On the other hand, With the increasing of talc percentage, density also rises. From the figure-9, 0 and 5% using of talc has the more similar result. But the using of highest percentage of talc attains the highest density value. So the using of talc has the positive impact on density.

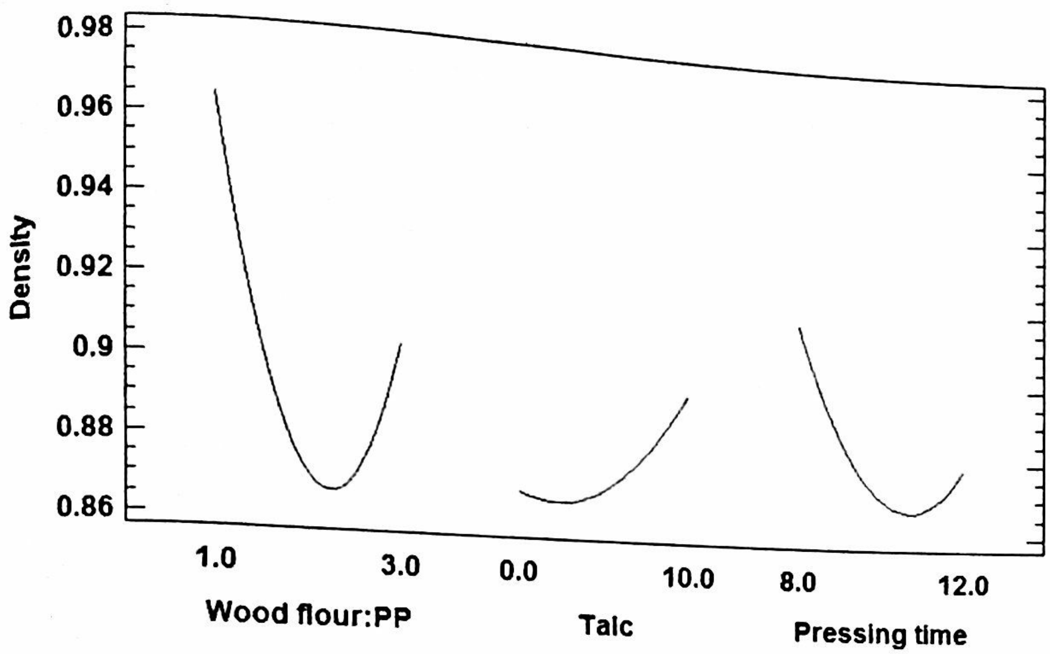

Figure 9 : Effect of processing variables on Density.

Wood fibers are composed of various organic materials (primarily cellulose, as well as hemicellulose and lignin) and therefore their thermal treatment leads to a variety of physical and chemical changes. Thermal degradation of those fibers leads to deterioration of their physical and mechanical properties. It also results in the generation of gaseous products, when processing takes place at temperatures at 180° C or above, which can create high porosity and low density (Georgopoulos et al. 2005; Jacob and Thomas, 2008). In wood-plastic composites, talc is used to improve stiffness and to reduce porosity (Noel and Clark 2005; klyosov, 2007). It increases the bonding capacity between plastic and wood fiber. Noel and Clark, (2005) shown that talc (up to 30%wt) can have a positive effect on modulus, strength, processing efficiency, creep and elastic recovery performance of WPCs. Similar result is found in this study that using high percentage of talc increases the board density.

4.2.2 Factors Affecting on Moisture Content

Following figure-10 demonstrated that with the increasing of wood-plastic ratio and talc percentage, the MC curve straightly decreases. Endra et al. (2012) stated that wood consists mostly of vessels in which moisture is absorbed. But plastic that has hydrophobic nature and tends to impede the entry of water into plastic board. Talc has also the nature of hydrophobic (Kim et al. 2010) and also decreases the MC with the presence of higher percentage.

Pressing time has not so effective as well as wood plastic ratio and talc content on MC. Figure-10, shows the linear relationship between pressing time and moisture content. But moisture content increasing very slightly with the increasing of pressing time. It's might be happened that increasing pressing time breakdown the structural bond of plastic and also increases the water affinity due to chemical bond with wood.

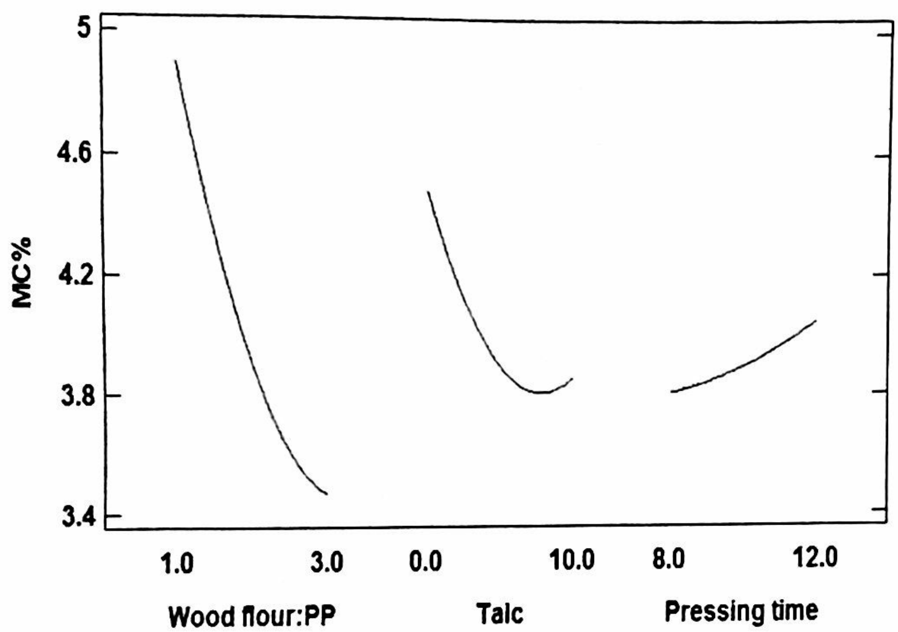

Figure 10 : Effect of processing variables on Moisture Content.

4.2.3 Factors Affecting on Shrinkage

A shrinkage property is very important to evaluate the board quality. All the processing parameters highly associated with this property. In wood-plastic ratio high wood content shows the high shrinkage property. With the increasing of plastic content shrinkage property is decreased. Reduction of shrinkage is due to increased hydrophobicity, they hardly react with hydroxyl groups of cellulose molecules in wood. Since most plastic monomers are non polar, there is little if any interaction with the hydroxyl groups attached to the cellulose molecule. In general, plastic monomers simply fill the capillaries, vessels, and the other void spaces and being polymerized in the wood structure (Mathias et al. 1991). High pressing time treatment of plant fibers with hydrophobic chemicals can reduce the moisture gain (Gassan and Bledzki, 2000; Espert et al. 2003). Similar result has found in this study, which has shown in the following figure-11.

From figure-11, talc shows irregular behavior with shrinkage property. Talc particles are normally plate-like. The structure of talc is characterized by a hexagonal sheet arrangement of silicon–oxygen tetrahedral groups linked in a common plane. The double-sheet units are easily separated by slight forces that result releases hydroxyl group (Rohl et al., 1976; Pooley & Rowlands, 1975). Hydroxyl group is the main cause to affinity moisture. So, using high percentage of talc can increases shrinkage quality.

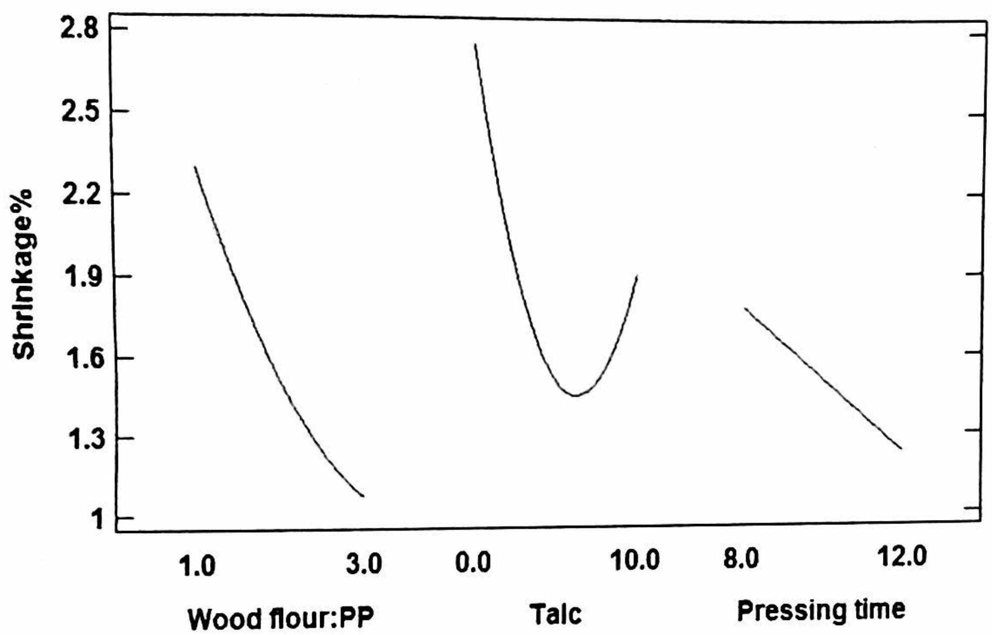

Figure 11 : Effect of processing variables on Shrinkage.

4.2.4 Factors Affecting on Swelling

The high moisture absorption of plant fibers leads to swelling and presence of voids at the interface (porous products), which results in poor mechanical properties and reduces dimensional instability of composites. Treatment of plant fibers with hydrophobic chemicals (i.e. Polypropylene) can reduce the moisture gain (Gassan and Bledzki, 2000; Espert et al. 2003). Similar result is found in this study, i.e. swelling properties decreases with the increasing of plastic content.

Talc percentage also shows the irregular behavior with swelling property. It's happen due to the structural change of talc with the variation of pressing time that earlier discuss in shrinkage part.

High pressing time causes the thermal degradation of fiber structure and build up a new bonding particles with plastic (Gassan and Bledzki, 2000; Espert et al. 2003). These composite board has achieved the lower water affinity character which reduces the swelling behavior.

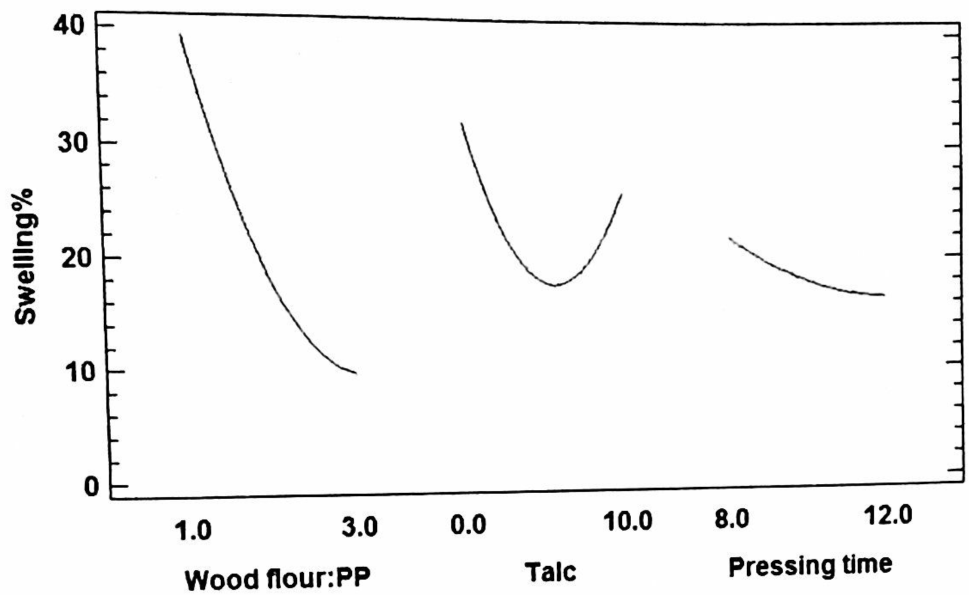

Figure 12 : Effect of processing variables on Swelling.

5. Conclusion

In this work, particles and fibres from *Pongamia pinnata* along with polypropylene as additives used to make experimental WPC panels. In the light of the preliminary results of this study both physical and mechanical properties of the samples were improved with addition of talc as filler into the panels. Box–Behnken response surface design is successfully employed to optimize and study the individual and interactive effect of process variables such as wood-plastic ratio, pressing time and talc percentage on the WPC board. The results indicated that the application of process variables had a significant effect on the maximum yield of WPC board. Model summary statistics showed that, developed model is adequate and precise with the experimental data. Analysis of variance showed a high coefficient of determination value which ensuring a satisfactory fit of the developed second-order polynomial regression model with the experimental data. The optimum conditions were found to be, wood-plastic ratio is 3, talc percentage 2.5% and pressing time 9 min and also the predicted maximum yield of MOR is 26.88N/mm^2 and for MOE is 1210.01N/mm^2. Under these optimized conditions the experimental values of WPC board agreed closely with the predicted yield.

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