Düzce Üniversitesi
Bilim ve Teknoloji Dergisi

Effect of Different Wood Flake & Chip Species On The Characteristic Features of Cement-Bonded Particle Boards

Lütfullah GÜNDÜZ [a], Şevket Onur KALKAN [a,*], A. Münir İSKER [b], Sibel HACIOĞLU [b], Özge ALTINYOLLAR [b]

[a] *Department of Civil Engineering, Faculty of Engineering and Architecture, İzmir Katip Çelebi University, İzmir, TURKEY*

[b] *TEPE BETOPAN Yapı Malzemeleri San. ve Tic. A.Ş., Ankara, Turkey*

** Corresponding author's e-mail address: sevketonur.kalkan@ikc.edu.tr*

ABSTRACT

This paper presents technical properties of the cement-bonded particle boards produced with different types of woods. Cement-bonded particle board (CBPB) is a composite product that is produced by pressing a mixture of wooden particles (chips/flakes) and Portland cement as the binding agent and hydration additives. A comprehensive experimental research work was carried out to analyze the technical properties of the cement-bonded particle boards produced with the chip and flake components obtained from different types of woods. In this research, some technical parameters such as physical sizes, material matrix structures, wood-cement compatibility, mechanical strength and stability properties were examined. Some research findings are presented here and the effects of these parameters on the use of the product were also discussed.

Keywords: *Wood, Chip, Cement, Particle Boards, Features, Production, Styling.*

Farklı Yonga Türlerinin Çimentolu Yonga Levhaların Karakteristik Özellikleri Üzerine Etkileri

ÖZET

Bu çalışmada farklı ağaç türleri ile üretilen çimento bağlayıcılı yonga levhaların teknik özellikleri sunulmaktadır. Çimento bağlayıcılı yonga levhalar (CBPB), bağlayıcı ajan ve ahşap parçacıklarının karışımı ile preslenerek üretilen kompozit bir üründür. Bu bağlamda, farklı ağaç türlerinden elde edilen yonga bileşenleri ile üretilen çimento bağlayıcılı yonga levhaların teknik özelliklerini analiz etmek için kapsamlı bir deneysel araştırma çalışması yürütülmüştür. Bu araştırmada, fiziksel boyutlar, malzemelerde çimeto matris yapıları, yonga çimento uyumluluğu, mekanik dayanım ve stabilite özellikleri gibi bazı teknik parametreler incelenmiştir. Bazı araştırma bulguları burada sunulmuştur ve bu parametrelerin ürünün kullanımı üzerindeki etkileri de tartışılmıştır.

Anahtar Kelimeler: *Ahşap, Yonga, Çimento, Yonga Levha, Özellikler, Üretim, Şekillendirme.*

Received: 10/01/2018, Revised: 18/03/2018, Accepted: 03/04/2018

I. Introduction

Wood-cement composites are widely utilized in many countries for both interior and exterior applications because of their strength properties for building materials (e.g., siding, roofing, cladding, fencing and sub-flooring) and for acoustic properties such as in highway sound barriers [1]. These composites have unique advantages over other conventional materials. Generally, these products combine the good qualities of cement (relatively high resistance to water, fire fungus, and termite infestation coupled with good sound insulation) with those of wood (high strength to weight ratio, nailability and workability [2, 3, 4].

Cement-bonded particle board is a composite product that is produced by pressing a mixture of wooden particles (chips/flakes) and Portland cement as the binding agent and hydration additives. In recent years, some products for structural applications have been developed such as cement-strand slab, cement-bonded composite beams and cement-bonded oriented strand boards. In comparison to wood and conventional wood products, cement-bonded particle boards are highly fire resistant, having a high mechanical strength, water & moisture and insects resistant especially in warm and humid environment where such materials are demanded for construction materials and ecological cleanness required at the same time. They are best suited for the floor systems, attic adaptations and the loft superstructures, ventilated façades, fire protection applications, fascias, ceilings, walls and partitions and different small garden items. Wood-cement composite sheets as known were first produced in Austria in the 1930s under the name Heraklith and made of material in the form of shavings. Magnesite was first used as a binder material for the production and then Portland cement was used instead of magnesite at a later time. In the history, the first cement chipboard factory was established in Switzerland in 1967. The first facility in Turkey started operation in Arhavi in 1987. Today, however, the only production system established in Turkey is still in Ankara [5].

Cement bonded particle boards have treated wood chips and/or flakes as reinforcement. As chip and/or flake sizes are important parameters in terms of reinforcing properties, the species of wood from which the chip and flakes are obtained is as important as the least size feature. Today, many types of derivative chip and flake materials, from bamboo to pine tree species, are being used as reinforcing elements in these productions. However, according to tree species, the technical specifications of the cement-bonded particle boards are inevitable to change.

II. Cement Bonded Particle Board Manufacturing And Wood Species

Cement bonded particle boards are products manufactured from a mixture of Portland cement, chemical additives and particles generated from lignocellulosics [4]. Therefore, the particleboards are designed as a composite material or mixture containing two phases; cement paste and wood chips. For this reason, the main input materials in production are cement and chip. The most important factor affecting the quality of the board used in the production of cement bonded particleboard is the type of wood, chip shape and size that the chip is produced. Another important factor, however, is the period for curing of the cement used in production.

As the main raw materials in production of CBPBs, lignocelluloses are usually obtained from three separate sources: using different wood species, some agricultural waste and industrial residues. The some particles as residues are coir, sugar cane bagasse and cotton stalks. Cement bonded particle boards seem attractive in extending the use of wood waste and agricultural residues. Several attempts were made in the past to mix different types of raw materials for particleboard manufacture. This was done to make use of lignocellulosic residues and or to improve or modify the quality of particleboard [6].

The wood to be used in production should be groats, noncarious and long fiber softwood. The wood in these properties could be usually obtained from beech, oak, fir, bamboo, pine, chestnut and walnut tree species. The most commonly used tree among these tree species in Turkey is the pine tree. The pine tree is also known as Pinus. Pine tree is a coniferous tree species from the family of pine trees. It is known that today there are 115 kinds of pine tree species. In Turkey, there are five species of pines with short leaves all of which have two leaves including *Pinus brutia*, *Pinus halepensis*, *Pinus nigra*, *Pinus pinea* and *Pinus sylvestris*.

In particular, *Pinus sylvestris* species grow mostly in the Black Sea region. The pine trees that keep their green nature are usually grown in tropical regions and mountainous areas. They do not shed their leaves in the winter. It is also a pine species that has a general spread in Caucasus, Siberia, North Asia and almost everywhere in Europe. In Turkey, the location of the *Pinus sylvestris* is quite high. It develops quickly in convenient places. It is also resistant to cold weather and wind. *Pinus nigra* often set up pure or mixed forests in the upper reaches of coastal areas, and also go up to the steppes. It is a type of tree with plenty of resin. Needle leaves are dark green and hard. It is preferably used pine tree species in production of CBPBs. *Pinus pinea* is also a type of pine which is widely spread in Aegean and Mediterranean coasts, Spain, Italy, Crete and Turkey. The young have a round, elderly appearance as a scattered umbrella. On the other hand, *Pinus brutia* is one of the most important tree species of Turkey, which is extremely resistant to drought and grows successfully in different soil conditions. Young shoots are thick and red. *Pinus brutia* is one of the most widely used pine tree species in production of CBPBs. *Pinus halepensis* is a pine species unique to the Mediterranean region. This species is usually grown in Morocco, Italy, Spain, Italy and Turkey. Their shells are orange and red in color. Their leaves are yellowish green. It is preferably used pine tree species like *Pinus nigra* in production of CBPBs.

According to the general characteristics of these pine tree species, the chip size and characteristics obtained may vary. Among the most effective properties are the lignin and resin content of the wood, the fibrous vascular structure of the tree is a property that determines the fibrillar form of the chip. During shredding of the chip, the fibrous thickness of the chip and the fibrous texture of this thickness value are affected by this form. With the general technical experience gained, more rational chip particles can be generated from *Pinus brutia* and *Pinus nigra* species due to their structural forms. Besides the lignin and resin content of the wood species, the sugar content of wood is considered as a very important factor in production of CBPBs. However, there is a significant restriction on sugar rates. It is desirable not to exceed 4% of the sugar content in the wood composition. However, it is negligible that this sugar content should be less than 1% for a high quality plate production. The high sugar content of wood is the main factor affecting the negative bonding wood with cement. Cement hydration; water, heat and alkaline environmental conditions is a rather complicated reaction. Glucose and extractive content in the wood affects this hydration negatively [7]. The reduction of the extractive substance, and in particular the glucose content, can be achieved by a series of pre-treatments. For this purpose; chemical treatment such as dissolving in 1% NaOH solution or in to cold-hot water can be applied [8]. However, production costs increase due to these chemical processes. Therefore; wood species with low sugar content are preferred in the production of CBPBs. Species such as pine, fir and spruce cut in autumn or winter times are widely used. Wood species like eucalyptus, acacia and poplar could be used after the neutralizing the extractives. But, wood species such as *Alnus glutinosa* and *Larix decidua* are not preferred due to containing high sugar ratios by weight of 0.25% glucose, sucrose and xylose in their structure [9]. Therefore, the chips used in this experimental study were kept in hot water before the inclusion of the mixture. The sugar content of the chips was reduced with this method. Total glucose, sucrose and xylose amount of the samples produced with *Pinus brutia* flakes or *Pinus sylvestris* flakes was found to be below the average concentration of 0.25% by weight.

The compatibility of lignocellulosic materials with cement can be enhanced by several treatments. Hot water and weak alkali are among the common treatments used to extract the inhibitory substances in wood. Calcium chloride is one of the widely used accelerators of cement setting [6]. In the early 1880s, $CaCl_2$ was used as a chemical additive in the blends to accelerate cement hydration. $CaCl_2$ is widely used because of its effective and easy availability. But, $CaCl_2$ causes chlorides, which cause co-precipitation on metal surfaces, to become clear. This creates problems in practice and requires the use of galvanized nails and screws to counter the risk of corrosion [10]. Other than these in the production of cement bonded particle boards, chemicals such as Magnesium chloride $MgCl_2$, Potassium silicate, K_2SiO_3, sodium silicate Na_2SiO_2 and aluminum sulphate $Al_2(SO_4)_3$, $FeCl_3$, Na_2CO_3, $NaHCO_3$ and lime water [5] are also used to accelerate cement bonding with wood. Accelerators are usually added together with water before the wood wool is mixed with the cement. Its concentration is 1-5% of the weight of the water.

All chipboards produced for use within the scope of this study were produced by preparing constant mixture ratios. These mixing ratios are as follows; chip amount is 21% by weight, Ordinary Portland cment amount is 24% by weight, filling material amount is 47.2% by weight and chemical admixture amount is 7.8% by weight. The variable material in the mixture combinations is chosen only as the type of the chip. The unit volume weights of the samples were measured in accordance with the requirements of TS EN 634-2. The unit volume weight of the samples produced with *Pinus brutia* flakes were found to be 1280 kg/m^3 and the unit volume weight of the samples produced with *Pinus sylvestris* flakes were found to be 1265 kg/m^3 on average.

III. THE INFLUENCE OF PHYSICAL PARAMETERS FOR THE PRODUCTION

Although there are several technical mixing parameters such as wood/cement ratio, water/cement ratio and cement/chemical additive ratio, many physical parameters are also influential in the production of CBPBs. For example; wood flake and chip fiber dimension, chip thickness and fiber structure, fine and coarse chips. These parameters are all belongs to the wood species. Although a similar wood fiber preparation unit is used, the physical properties of the chips obtained according to the wood type may vary.

At the beginning of the most important physical greats in the production of CBPBs are the dimensions of prepared chips. Very thick chips are generally not preferred in the production. Instead, long chip shapes with thin and fibrous properties are preferred in production runs.

Fine flaked wood chips are generally preferred in the upper and lower splashes of the CBPBs, while coarse flaked wood chips can be used in center core splash in the production of CBPBs. *Pinus brutia* and *Pinus sylvestris* species are seen as species capable of providing the fine and long fiber length. Fine and coarse wood chips generated from *Pinus sylvestris* and *Pinus brutia* species are symbolically shown in Figure 1 to Figure 4, respectively.

Figure 1. *Fine wood chips (Pinus sylvestris).*

Figure 2. *Coarse wood chips (Pinus sylvestris).*

Figure 3. *Fine wood chips (Pinus brutia).*

Figure 4. *Coarse wood chips (Pinus brutia).*

As evaluating the Figure 1 to Figure 4, it could be seen that fiber textures of *Pinus brutia* are more prominent comparing the fiber textures of *Pinus sylvestris* type. This feature also represents the possibility of giving the higher flexibility for the particleboard. On the other hand, due to structural nature of *Pinus brutia*, higher water retention can also indicate that chip particles will provide a more successful result for the cement hydration reaction. This could actually be shown as a wood-cement bonding for fine and coarse chips for *Pinus brutia* type in Figure 5 and Figure 6, respectively.

These figures show the surface adhesion in *Pinus brutia* chips after the cement hydration and also the bond formation performance. Cement hydration process is successful and it can be seen that the materials forming the matrix structure of the mixture forms a strong adhesion on the chip surfaces. It can also be clearly seen that thin and long chip lengths play a more active role.

Figure 5. *Wood-cement bonding.*

Figure 6. *Wood-cement bonding.*

IV. The Influence Factor of Wood-Cement Compatibility

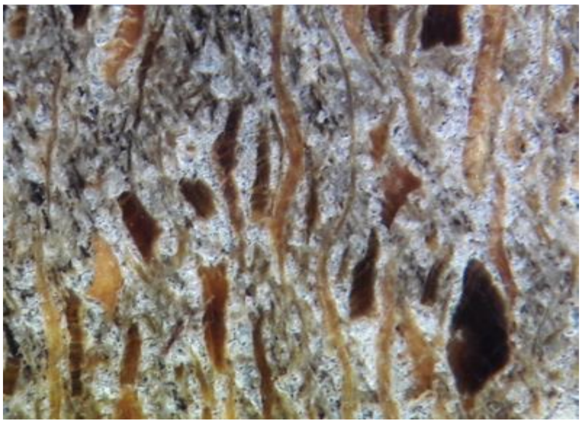
Wood-cement compatibility is affected by several factors such as type of species, type of cement, part of the tree, season during wood-cutting, wood/cement ratio, storage condition and so on [11]. Generally, lower amount of inhibitory extractives diffuse into the cement paste is beneficial for the wood-cement compatibility [12]. Different wood species contain different kind and amount of wooden extractives, so they have different effect on cement hydration with some completely preventing cement setting. In general, hardwoods are generally less compatible than softwoods because of the presence of large amount of soluble xylan in hardwoods [12, 13].

In a conducting research study, 5 different pine species were analyzed on the plate testing samples of the fixed mix prepared for wood-cement compatibility in the form of thin and thick chips. In addition to analyzing the bending strength, compressive strength and elastic modulus values of the obtained test specimens, the compatibility of chip-cement paste was also investigated macroscopically in matrix structure. In this part, the compatibility between the wood flake-cement observed from macroscopic examinations and the causative factors are briefly discussed. More meaningful results can be obtained when the distribution of chips and their orientation in the matrix structure are generally macroscopically examined on the plate thickness. When the cross-sectional thickness is examined, thin and long shaped chips are seen to be distributed more regularly in the matrix structure. In addition, thin and fibrous forms of chips show high reinforcement effect and matrix fill. If enough cement is found in the mixture, it can be seen that the wood-to-cement compatibility in the vicinity of thin and long chips is easier to achieve and that there is no disagreement at the contact points. This positive interaction has been found to be much more evident in the use of chips generated from *Pinus brutia* and *Pinus sylvestris* species. These effects are shown in Figure 7 and Figure 8 for *Pinus brutia* and *Pinus sylvestris* species, respectively.

Figure 7. *Wood-cement compatibility effect.*

Figure 8. *Wood-cement compatibility effect.*

However, it has also been observed that the use of wood chips obtained from oak wood and chestnut wood may have a much higher level of performance in this interaction. Even especially when used in thicker form of chips generated from chestnut wood, it can also be seen that the matrix exhibits an upper segment in terms of frequency and compatibility. A representative view of this phenomenon is presented in Figure 9 and Figure 10 for oak wood and chestnut wood species, respectively.



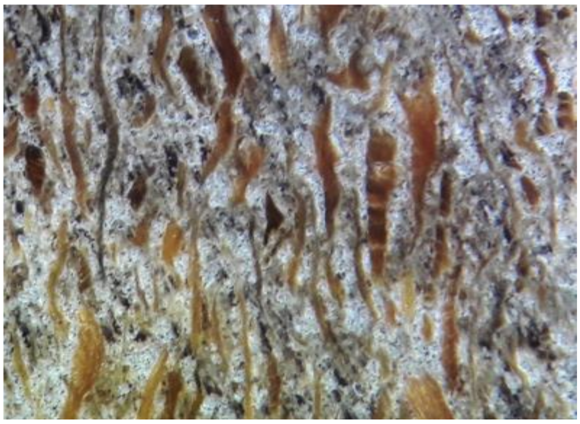


Figure 9. *Matrix form by oak wood chips.* ***Figure 10.*** *Matrix form by chestnut wood chips.*

The use of wood chips in a rather thick form in the matrix structure, if the process is not about adequate compression, weak zones usually form around the chip in the connective tissue and pore-shaped openings occur. This is usually an unwanted feature. Because it has an effect reducing the compressive and bending strength values of the CBPBs. The value of this strength reduction can reach up to 20% depending on the opening ratio. An example of this effect is shown in Figure 11. Another negative interaction for chips is internal opening due to chip thickness. The opening in the chip particle due to the fibrous texture of the wood shows a significant effect increasing the pore formation in the matrix structure. This is actually an important factor to increase the water absorption value and the dimensional stability of the product. The development of this phenomenon in the product matrix structure allows the product to exhibit swelling properties over time as well as the strength values of the product are reduced. An example of this effect is also shown in Figure 12.

Figure 11. *Matrix form of a CBPB sample.* ***Figure 12.*** *Matrix form of a CBPB sample.*

As the particle size and diameter increase in the matrix structure, water absorption capacity tends to increase due to the fibrous property of the wood forming the particle. In other words, the water absorption capacity of the material increases as the chip particle surface per unit area in the matrix structure increases. This size growth of the chips creates pores in the contact surface between the matrix structure and the chip particle (Fig. 11). Due to these pores, the matrix structure is also increasing its ability to absorb water. So the diameters (widths) of the chips to be included in the mixture should be idealized. It is desirable that the diameter of the chip, which can be idealized according to the findings of the examination, should not exceed 300 microns in thickness. Every 10%

increase over this thickness value corresponds to an average of 0.75% more water absorption value in both types of chip board products.

According to TS EN 789, the compressive strength of the samples produced with *Pinus brutia* flakes were found to be 17.8 MPa on average and the compressive strength of the samples produced with *Pinus sylvestris* flakes were found to be 16.3 MPa on average. The bending strengths of the specimens were tested and determined according to TS EN 634-2. The modulus of rupture (MOR) of the samples produced with *Pinus brutia* flakes were found to be 12.6 MPa on average and the MOR of the samples produced with *Pinus sylvestris* flakes were found to be 11.8 MPa on average.

The fact that is generally obtained in research findings can be observed as a positive factor in terms of compressive strength as the thickness of the chip used in the matrix structure increases. In the context of the chip type used, in the chips produced from *Pinus brutia*, a 3% increase in chip thickness resulted in a 4.5% improvement in average compressive strength of CBPB. When this assessment was made for *Pinus sylvestris*, a 3% increase in chip thickness resulted in a 2.7% improvement in average compressive strength. Another mechanical examination on the samples is to examine the specimens in terms of MOR. When the samples were examined in terms of MOR value, the increase of the fiber length and simultaneously decrease in fiber diameter value of the chip (thin and long dimension chip) were observed as a general factor that increasing the modulus of rupture. Similar to compressive strength evaluation, in the use of *Pinus brutia* type chips, a 5% increase in chip thickness resulted in a 1.3% improvement in average MOR values. When this assessment was made for *Pinus sylvestris*, a 5% increase in chip thickness resulted in a 1.1% improvement in average MOR values.

V. CONCLUSIONS

In this paper, effect of different wood flake and chip species on especially physical characteristic features of cement-bonded particle boards were investigated. Biological and chemical structure of the wood flakes and chips were discussed. Effect of fiber sizes and cement hydration process were examined. As a result of these properties, the probable effects on the physical, mechanical and product quality properties of different wood flake and chip species have been examined microscopically. Wood flake and chip fiber dimension, chip thickness and fiber structure, fine and coarse chips were found as important factors that effects the physical and mechanical properties of the final product. As the particle size and diameter increase in the matrix structure, water absorption capacity tends to increase due to the fibrous property of the wood forming the particle. Size growth of the chips creates pores in the contact surface between the matrix structure and the chip particle. It is found as a positive factor that compressive strength increases as the thickness of the chip used in the matrix structure increases. When the samples were examined in terms of MOR value, the increase of the fiber length and simultaneously decrease in fiber diameter value of the chip were observed as a general factor that increasing the modulus of rupture. In addition, thin and fibrous forms of chips show high reinforcement effect and matrix fill.

VI. References

[1] A.A. Moslemi, "*Emerging technologies in mineral-bonded wood and fiber composites*", Adv. Perform. Mater. 1999, 6, 161-179.

[2] S. Iwakiri , Paineis de Maderia Reconstituida; FUPEF:Curitiba, 2005.

[3] A.O. Olurunnisola, "*Effects of Husk Particle Size Clacium Chloride on Streght an Sorption Properties of Cocounut Husk – Cement Composites*", Ind. Crops. Prod. 2009, 29, 593-598, Available from http://dx.doi.org/10.1016/j.indcrop.2008.09.009.

[4] H.S. Tunior, J. Fiorelli and S.F.D.Santes, "*Sustainable and Nonconventional Consruction Materials Using Imnorganic Bonded Fiber Composites*", WP Woodhead Publishing Series in Civil and Structural Engineering, 2017, 494 pp, Brazil.

[5] H. Kalaycıoğlu, H. Yel ve A.D. Çavdar, "Çimentolu Odun Yünü Kompozitleri ve Kullanım Alanları", *Kastamonu Üniversitesi Orman Fakültesi Dergisi*, c. 12, s. 1, ss. 122-133, 2012.

[6] T.E. Mohamed, A.Y. Abdelgadir, M.M. Megahed and R. Nasser, "Effect of Mixing Three Lignocellulosic Materials with Different Cement Ratios on the Properties of Cement Bonded Particleboard", *Journal of Science and Technology*, vol. 12, no. 3, 12, pp. 44-54, 2011.

[7] H. Kalaycıoğlu, "Sahil Çamı (Pinus pinaster) Odunlarının Yonga levha Üretiminde Kullanılması İmkanları", Doktora Tezi, KTÜ FBE, Trabzon, Turkey, 1991.

[8] M.H. Simatubang, A. Geimer, L. Robert, "Inorganic Binder for Wood Composites: Feasibility and Limitation, Wood Adhesives", *Forest Product Societies*, Madison, Wisconsin, pp. 167-176, 1990.

[9] *M. Aro, "Wood Strand Cement Board", 11th Int. Inorganic-Bonded Fiber Composites Conference (IIBCC2008), November 5-7, 2008, Madrid, Spain.*

[10] A., Lee, Z. Hong, "Compressive Strenght of Cylindirical Samples as an Indicator of Wood-Cement Compatibility", *Forest Products J.*, vol. 36, no. 11, pp. 59-62, 1994.

[11] S.R. Karade, L.K. Aggarwal, "Cement-bonded lignocellulosic composites for building apications", *Metals Materials and Processes*, vol. 117, no. 2, pp. 129-140, 2005.

[12] B. Na, Z. Wang, H. Wang, X. Lu, "Wood -cement compatibility review", *Wood Research*, vol. 59, no. 5, pp. 813-826, 2014.

[13] R.C. Weatherwax, H. Tarkow, H., "Effect of wood on the setting of Portland cement", *Forest Products Journal* , vol. 14, no. 12, pp. 567-570, 1964.