Study on Mechanical Properties of Lightweight Panels Made of Honeycomb and Polyurethane Cores

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In response to the increasing use of lightweight and durable raw materials in the manufacture of furniture for home and office, in this study, the effect of the skin type (MDF with a thickness of 3, 6 and 8 mm, particle board, plywood with 3 and 5 layers), the core type (polyurethane foam and Kraft paper honeycombs), and core thickness (3 and 4 cm) on mechanical strength of lightweight panels, were examined. The mechanical tests included bending strength, modulus of elasticity, impact bending, and compression. The results showed that the mechanical strength of lightweight panels made of polyurethane foam core, due to the higher density and good bonded with the skin, was better than lightweight panels made of kraft paper honeycomb core. By increasing the core thickness, the strengths of the panel was reduced. The best results were obtained in lightweight panels made of polyurethane foam core with a thickness of 3 cm and plywood skin.

Keywords: Lightweight panel; Honeycomb; Polyurethane; Mechanical properties

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INTRODUCTION

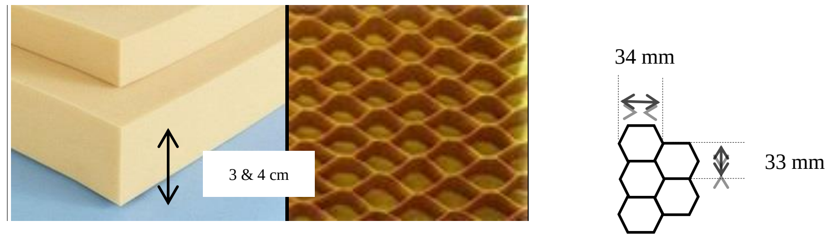
Sandwich structures are composed of two thin but stiff material as skins bonded to a thick but lightweight material as core. This presents a structure with properties for high bending stiffness with overall low density. Sandwich structures are usually used as an alternative material to achieve the same structural performance as conventional materials with less weight (Tan et al. 2011). Composites such as sandwich panels made of Kraft paper honeycomb core and wood composite skins were first introduced in industry in early 1900s. Compared to solid wood based panels, such as particleboard, medium density fiberboard (MDF), and plywood, lower material usage and lighter weight were the main advantages (Bitzer 1997; Pflug et al. 2004). Due to the relatively low cost of the wood materials and general consumers' preference for solid panels, these lighter weight alternatives did not gain much popularity in the market place for many decades. However, in recent years, with intensifying global competitive pressure as well as rising cost in wood material and energy, industries, such as furniture manufacturers, around the world become increasingly interested in using these types of alternative panels as product components for reduced raw material cost and usage. Some main advantages of these lightweight panels for furniture applications include reduced weight and packaging costs, less damage during transportation, improved work conditions on the shop floor and lower production costs (Wemlund 2004). Some manufacturers are also aiming to use these types of panels or structures for more demanding load-bearing conditions. Some examples are floors, decks, transportation pallets, load bearing walls, etc. (Mosbybuil 2010; Vinson 2005). Unfortunately, scarce studies can be found in the literature dealing with sandwich panels containing a kraft paper core and wood composite skins. Meanwhile, structural optimization has been carried out extensively for sandwich panels made from other materials, such as metals and polymers, since the 1940s. As a result, there is a large body of literature dealing with structure–property relationships for these types of structural sandwich panels (Gibson et al. 1998; Noor et al. 1996; Fortes et al. 1999). Since the material properties of the sandwich panel containing a Kraft paper core and wood composite skins significantly differ from those of aerospace structural sandwich panels, systematic studies of the structure–property relationships of sandwich panels containing a Kraft paper core and wood composite skins are needed. According to the classical sandwich theory (Plantema 1999; Allew 1969) for structural panels, the constraints imposed by the panels' skin layer could significantly affect the local deformation mechanism of the heterogeneous core. The impact of skin properties on the sandwich panels was first studied theoretically by Kelsey et al. (Kelsey et al. 1958). There is no published data on the influence of core type, core thickness, skin type, and thickness ratio of core to skin (shelling ratio) on the mechanical properties of the sandwich panels (Chen et al. 2011).However, an early Investigation of elastic moduli of Kraft paper honeycomb core sandwich panels shows that decrease in the thickness ratio of the core to skin layer (shelling ratio) resulted in an increase in the modulus of elasticity and shear modulus of the sandwich panels. The increase was significant when the shelling ratio was smaller than six (Chen et al. 2012). It is the aim of this study to investigate the mechanical properties of lightweight panels made of honeycomb and polyurethane foam cores.

METHODS AND MATERIALS

Sample Preparation

Three types of wood composites were used as a skin: MDF with a thickness of 3, 6 and 8 mm particleboard thickness of 8 mm and 5-layer and 3-layer plywood prepared. Two types of Core materials: Kraft paper honeycomb[1] with hexagonal cross section and cell size 34-33 mm and a nominal thickness of 3 and 4 cm, and polyurethane with 3 and 4 cm thickness was used.

The thermoplastic adhesive, polyvinyl acetate (PVA) was used (Table1). The frame was used to make lightweight panels. After gluing and joining the skin layers to the core, lightweight panels were placed under the hot press. Temperature 80 ° C, pressure of 60 kg/cm^2 and duration of 7 min were used for all panels. After the press, the lightweight panels were conditioned for 2 weeks (in 23± 2 ^{0} C, RH 65%).



A: Polyurethane foam:
Thikness:3 and 4 cm
Density: 0.035 g/cm^3

B: Kraft paper honeycomb:
Cell size: 33*33 mm
Weight:210 g/m^2
Thikness:3 and 4 cm
Density : 0.036 g/cm3

Fig.1. Core specification.

Mechanical Tests

To measure modulus of rupture (MOR) and modulus of elasticity (MOE) according to the standard ASTM C393 and loading speed of 2 mm per minute was used. To measure the impact strenght1 the standard DIN 52189 (1992), compression in accordance with ASTM C365-94 standard and the loading speed was 2 mm/min. Data analyzed according by factorial test using SAS software in 99% confidence level average rating according to Duncan's test was perform [Table 1].

Table 1. Details of Variable Factors (Core and Skin)

Core type	**Core thickness**	**Skin type**					
		Particle board	Medium density fiber board			Plywood	
		8 mm	3 mm	6 mm	8 mm	3 layer	5 layer
Polyurethane foam	**3 cm**	P3-Pb8	P3-M3	P3-M6	P3-M8	P3-PL 3	P3-PL5
	4 cm	P4-Pb8	P4-M3	P4-M6	P4-M8	P4-PL 3	P4-PL 5
Kraft paper honeycomb	**3 cm**	H3-Pb8	H3-M3	H3-M6	H3-M8	H3-PL 3	H3-PL 5
	4 cm	H4-Pb8	H4-M3	H4-M6	H4-M8	H4-PL 3	H4-PL 5

RESULTS AND DISCUSSION

Modulus of Rupture (MOR)

Figure 2 shows the effects of core and skin type and thickness on modulus of rupture (MOR).

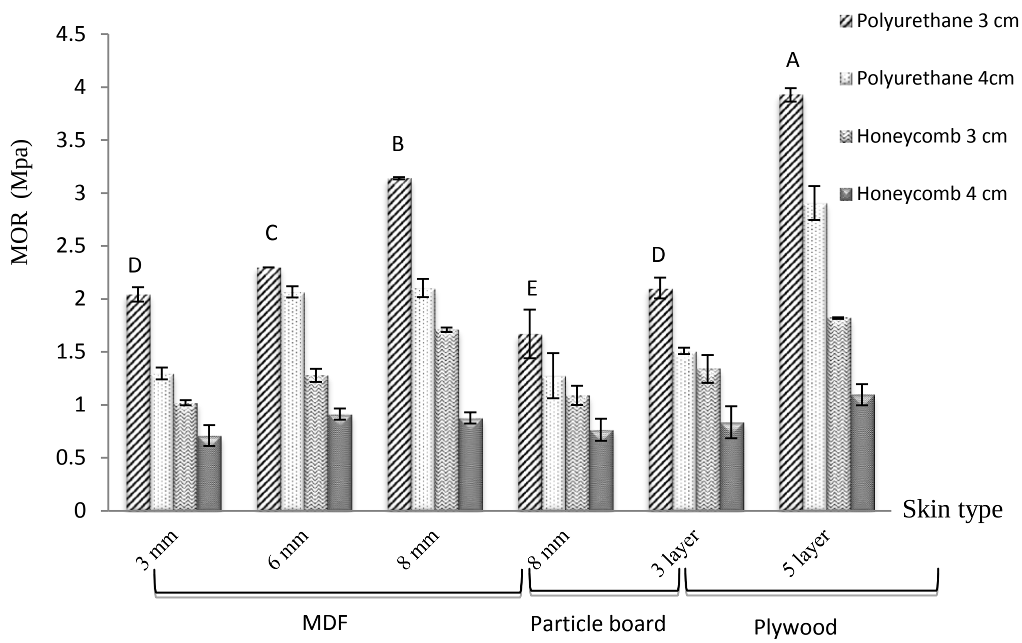


Fig. 2. Effect of core and skin type and thickness on modulus of rupture

Effect of core type and core thickness

The results showed that the effect of different core types and core thickness on the MOR was significant at the 99% confidence level. Figure 2 shows that the highest value of the MOR obtained in panels made of lightweight polyurethane core with a thickness of 3 cm and the least value of MOR obtained in samples made of Kraft paper core honeycombs with 4 cm thickness. According to figure 4-10 it can be concluded; the samples made from polyurethane core showed better MOR than Kraft paper honeycomb core and by polyurethane core, MOR increased up to 76/04 %, because of its more effective surface and so, better bonding of skins to the polyurethane core. Increase in the MOR was not only due to increase in the thickness of the core, but also the core type and the bonding effective surface between the skins and core had effects.

Effect of skin type and skin thickness

The results showed that the effect of different skin types and skin thickness on the MOR was significant at the 99% confidence level. Generally the MOR of particleboard is less than MDF and plywood (Cai et al. 2010). In this study, results showed the same pattern. Figure 2 shows that the highest value of MOR obtained in lightweight panels made of 5-layer plywood skins and least value of MOR obtained in panels were made of particle board skins. Plywood has more load bearing capacity comparing MDF and particleboard. In MDF skin type panels, MOR was increased by increasing the skin thickness. Panel density has a direct influence on the bending strength, because with increasing the density of wood substance per unit volume and resistance to force increases more and As a result, bending strength and modulus of elasticity increases .. Shalbafan et al. (2011) concluded that by increasing the thickness of the lightweight panels, the modulus of rupture and modulus of elasticity increased (Shalbafan et al. 2011).

Modulus of Elasticity (MOE)

Figure 3 shows the effects of core and skin type and thickness on modulus of elasticity (MOE).

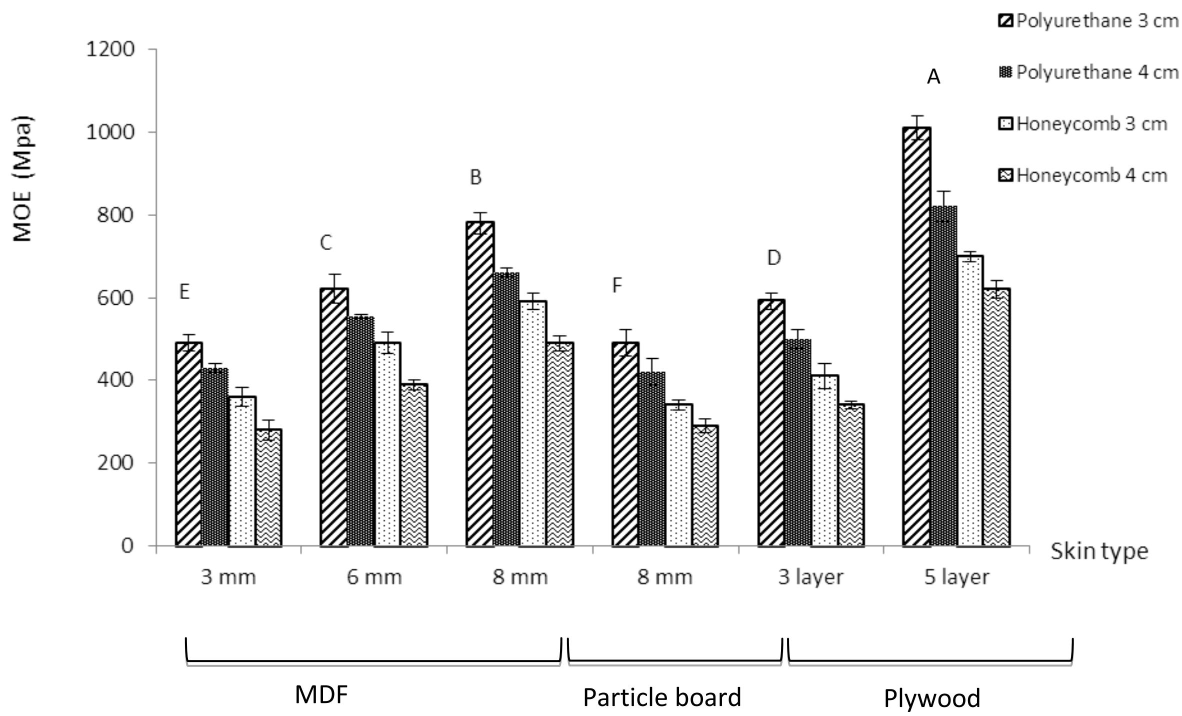


Fig. 3. Effect of core type and core thickness on modulus of elasticity (MOE)

Effect of core type and core thickness

The results showed that the effect of different core types and core thickness on the MOE was significant at the 99% confidence level. Figure 3 shows that the highest value of the MOE obtained in panels made of lightweight polyurethane core with a thickness of 3 cm and the least value of MOE obtained in panels made of Kraft paper honeycomb core with 4 cm thickness. According to figure 3 it can be concluded; the panels made from polyurethane core showed better MOE than Kraft paper honeycomb core and by polyurethane core, MOE increased up to 36/59 %, because of its more effective surface and so, better bonding of skins to the polyurethane core and Increasing the core thickness in both types of cores decreased the MOE values. Chen et al (2012) study on the MOE of sandwich panels made of kraft paper honeycomb core and results have shown too that a decrease in the thickness ratio of the core to skin layer (shelling ratio) resulted in an increase in the MOE and shear modulus of the sandwich panels (Chen et al 2012).

Impact Resistance

Figure 4 shows the effects of core and skin type and thickness on impact resistance.

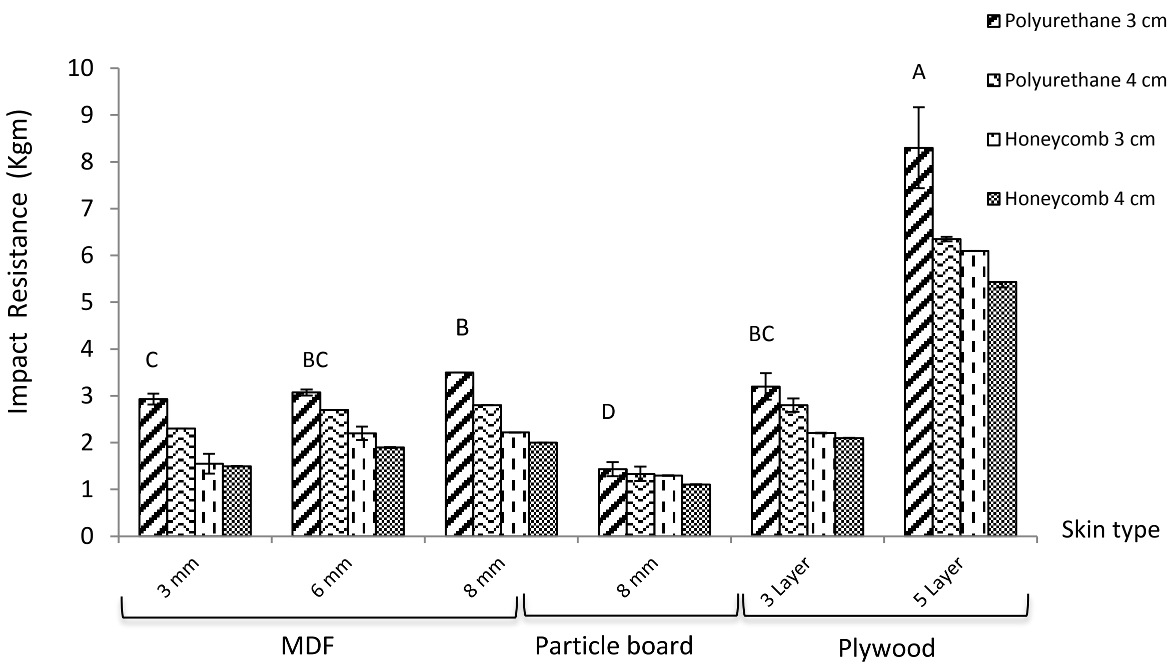


Fig.4. Effect of core type and core thickness on impact resistance.

Effect of core type and core thickness

The results showed that the effect of different core types and core thickness on the impact resistance was significant at the 99% confidence level. Figure 4 shows the highest value of impact resistance obtained in light weight panels made of polyurethane core with a thickness of 3 cm, and the least value of impact resistance obtained in panels made of Kraft paper honeycomb with a thickness of 4 cm. According to Figure 4 it can be concluded; the samples made from polyurethane core showed better impact resistance than kraft paper honeycomb core and by polyurethane core, impact resistance values increased 35/63 % because of its more effective surface and so, better bonding of skins to the polyurethane core and increasing the core thickness in both types of cores decreased impact resistance. The core has a significant influence on the of impact resistance, because the honeycomb core is absorbed about 50 to 95 percent of the total energy, while the skins absorbs only 7 to 35% impact energy (Paulius et al. 2010). With increasing height of cell wall in honeycomb structure, absorption of energy in panel reduced and there was relation with the behavior of impact bending and size of cell wall (Wang et al. 2009). So with the using up polyurethane foam instead of Kraft paper honeycomb and also decrease in thickness of core from 4 to 3 cm, the impact resistance increased.

Effect of skin type and skin thickness

The results showed that the effect of different skin types on the impact resistance was significant at the 99% confidence level. The highest value of impact resistance obtained in lightweight panels made of 5-layer plywood skins and least of impact resistance value obtained in panels were made of particle board skins. Figure 4 shows that the impact resistance of the panels made of MDF skins with increasing skin thickness gradually increased and by increasing the number of layers of plywood, the impact resistance of panel increased. An increased impact on the plywood when layer thickness was increased (Latibary et al. 2000). The impact resistance of the lightweight panels made of particleboard skin and paper honeycomb core was more than the panel just made of particle board (Barboutis et al. 2005).

Compression

Figure 5 shows the effects of core and skin type and thickness on compression.

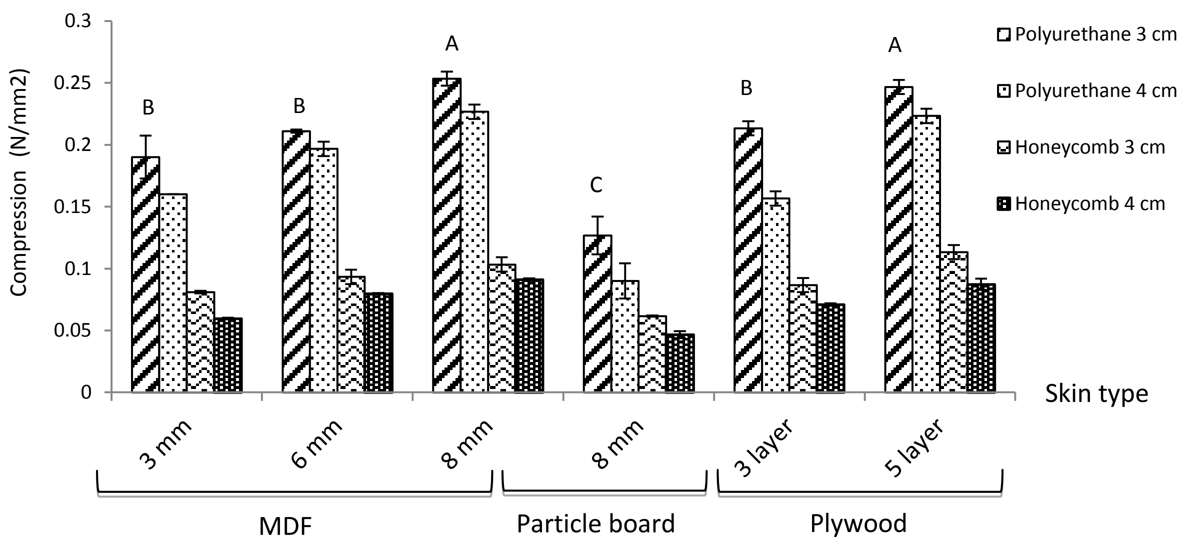


Fig.5. Effect of core type and core thickness on compression.

Effect of core type and core thickness

The results showed that the effect of different core types and core thickness on the compression was significant at the 99% confidence level. Figure 5 shows that the highest value of compression obtained in lightweight panels made of 5-layer plywood skin and with polyurethane core with a thickness of 3 cm and least value of compression obtained in panels were made of particle board with a thickness of 8 mm and kraft paper honeycomb core with thickness of 4 cm. According to Fig. 5 it can be concluded; the samples made from polyurethane core showed better compression than Kraft paper honeycomb core and by polyurethane core, compression values increased 129/63 %, because of its more effective surface and so, better bonding of skins to the polyurethane core and the force can spread out on the wide surface of the panel and increased panels compression strength. Increasing core thickness in both types of cores decreased compression. Polyurethane foam core was denser and harder than the paper honeycomb core and could obtained more against of load (Wang et al. 2009).In light panels with increasing cell wall height of kraft paper honeycomb, energy absorbing reduce. Also with increase in honeycomb cell wall thickness the value of energy absorbed per unit volume increases and compression increased and consequently the resistance increased (Erickson et al. 2005).

Effect of skin type and skin thickness

The results showed that the effect of different skin types on the compression was significant at the 99% confidence level. Figure 5 shows that the highest value of the compression obtained in panels made of 5-layer plywood skins and least value of compression obtained in panels were made of particle board skins. Figure 5 shows that, compression resistance of the panels increased by increasing the MDF skin thickness as a result of higher load-bearing (Khalili et al. 2009). The same results obtained in plywood skin type panels that increasing the number of layer lead to higher compression strength (Latibary et al. 2000).

CONCLUSIONS

Lightweight products were used as raw material in the manufacturing of, office furniture and home furniture industry is dramatically welcomed to Iran's manufacturers. In fact, these panels with lightweight have the ability to quickly assemble and have good resistance properties. In this study the results of mechanical properties of lightweight panels made of Kraft paper honeycomb and polyurethane foam cores as well as statistical analysis of data, can conclude that:

1. The mechanical strength of lightweight panels made of polyurethane foam core, due to the higher density and good bonded with the skin was better than lightweight panels made of Kraft paper honeycomb core.

2. By increasing the core thickness, the strengths of the panel was reduced.

3. The best results were obtained in lightweight panels made of polyurethane foam core with a thickness of 3 cm and plywood skins.

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