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Research Article

Investigation of the effect of CNT reinforcement on low-velocity impact behavior of wooden plate honeycomb aircraft structures

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ABSTRACT

In this study, with different thicknesses honeycomb aircraft structures and the application of multi walled carbon nanotube reinforcement (MWCNT) to their out surfaces the low-velocity impact behavior of with the effects of core height on the damage to the plates were investigated. In addition, it is aimed to determine the effects of nano composite coating on the surface structure and to investigate its usability in aircraft. In the research, an equal to two different samples number of samples taken from the wing structure of the aerobatic aircraft, 10 and 30mm thick, 100x150mm in size, one surface coated with wood and the other surface covered with %1 carbon nanotube (CNT), were applied impact test at 5 J energy level and analyzed comparatively with graphics. The tests were carried out at an impact speed of 1.2549 m/s. Because of the research, it was concluded that while the reinforcement of CNT in aircraft structures did not affect the weight increase within the limitations, it gave positive results in the increase of strength without disturbing the aerodynamic structure and increased the mechanical properties. The data obtained from the force-time, force-displacement and energy-time changes obtained from the experiments are explained with the help of graphics.

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Authorship contribution statement for Contributor Roles Taxonomy

Mustafa Taşyürek: *Writing, Investigation, Supervision, Conceptualization, Methodology, Formal analysis, Experimental studies.* **Okan Ödemiş:** *Writing, Visualization, Methodology, Experimental studies.*

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1. Introduction

It has become almost a necessity to use high-strength lightweight materials in all structures used in today's aircraft [1]. For this purpose, different composite structures are being developed by scientists to increase structural strength and reduce weight in aircraft. Sandwich structures with wooden plates are one of them. These structures have been used in aerobatic and agricultural aircraft and are currently used in various engineering fields. Aircraft structures may be exposed to various external factors during their service life. They can be exposed to impacts by foreign objects, especially during maintenance on the ground and during their stay in the air. While on the ground, mechanical maintenance tools and hard object impact during maintenance and service operations can be given as examples. In addition, impacts may occur because of foreign particles such as birds, stones and bolts during take-off and landing. For this reason, foreign body impacts on the composite structure in aircraft affect the structure negatively and create limiting factors on parameters such as performance and other aerodynamics depending on the operating conditions. Therefore, low-speed impact tests are very important for composite materials structures in aircraft.

In order to provide the desired lightness and strength in aircraft, honeycomb sandwich structures made of various materials are generally used [2]. Strength and lightness are the most important parameters for aircraft. In material technology, reducing weight can directly affect strength. This is an undesirable situation such as fragility and weakness. In this sense, it is important to determine the mechanical properties of the material. In this study, the CNT material, which has become one of the most interesting areas of modern science and technology, has been discussed and its applicability in the field of aviation, especially on aircraft structures, has been investigated.

Low-speed impact tests have been carried out experimentally in many areas related to sandwich honeycomb composites and CNT, and also analytical methods have been developed [3]. In addition, there are many experiments and researches in the literature related to CNTs as a reinforcement and bonding material. However, it has been revealed by experiments that CNT supplementation at certain rates gives positive results [4]. Rajoria and Jalili investigated the damping properties of CNT-epoxy composites with different properties for use in structural vibration applications [5]. In the test results, it was stated that MWCNT showed up to 700% absorbing ability in energy absorption compared to SWCNT. El Moumen and Tarfaoui investigated the effect of CNT on the mechanical properties of nano carbon reinforced laminated composites produced as textile composites. [6]. They found that the dynamic properties of composite panels increased by up to 13 % by adding 1 % CNT to the epoxy. They found that there was a decrease in dynamic properties from 4 % CNT reinforcement. They found that after a certain rate, the CNT reinforcement decreased the mechanical properties of the materials by exhibiting an opposite behavior instead of improving it. Zhu et al. tried to increase the CNT ratio by 1 % in order to improve the surface modification [7]. In this way, they observed that there was a 228 % increase in tensile strength, so that the surface treatment provided better load-bearing properties, but it caused structural failures such as fatigue. Increasing the amount of CNT excessively caused the formation of fatigue cracks on the material surface. They found that the effect of MWCNTs on crack growth rate was higher than that of SWCNTs. Safadi and Andervers, unlike the normal mechanical mixing method, used ultrasonic energy to disperse MWCNT homogeneously without agglomeration [8]. Using the Carreau equation, MWCNT was added to the polystyrene solutions without chemical pretreatment and it was determined that a homogeneous mixture could be formed at high shear speeds. In this way, they determined that there were improvements in material properties such as compressive, tensile, bending and impact strength. Uyaner et al. examined the effect of sample size on the low velocity impact behavior of E-glass/epoxy laminated composites and stated that increasing the sample width reduces the changes in volume on the sample. In this case, they reported that less collapse occurred, the impact time reduced and the contact force increased [9]. Esendemir and Caner experimentally investigated the impact behavior of layered composite materials in their study [10]. They investigated the factors that directly affect the damage formation such as sample thickness, striking tip geometry and ambient conditions, and revealed that choosing the small diameter of the striking tip and decreasing the plate thickness reduced the impact strength of the sample and caused puncture

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damage. Önal and Temiz experimentally investigated the low velocity impact behavior of balsa core sandwich composites with different layers and thicknesses at energy levels of 15 J, 30 J, 45 J and 60 J. [11]. They observed that increasing the number of layers increases the contact force and decreases the absorbed energy, while increasing the core thickness increases the absorbed energy. Erdoğan et al. experimentally investigated the low-velocity impact behavior of two different sandwich panels with 6061T6 aluminum surface plate with polypropylene PP/(C3H6) and polystyrene foam XPS/(C8H8) honeycomb core at energy levels between 25 and 100 J [12]. It has been seen in the experiments that plate thickness is effective in energy dissipation. In addition, they have proven that PP honeycomb is more successful in terms of preventing damage.

Taşyürek M. et al., in their study, reinforced high density polyethylene (HDPE) matrix with different ratios (1%, 3%, 5%) of MWCNT. Tensile test was carried out by producing nanocomposite mixture by injection technique. [4]. As a result, it was revealed that low MWCNT reinforcement had little effect on elongation at break for the determination of mechanical properties of notched and unnotched samples, and it gave positive results at 5% MWCNT reinforcement. In addition, they proved by their experiments that MWCNTs also prevent the proliferation of cracks in the matrix during stripping. In another study conducted by Taşyürek and Kara, the low velocity impact behavior of filament wound open-ended pipes reinforced with CNT was investigated. It has been reported that increasing the CNT reinforcement ratio decreases the impact damage area in tests performed with 10 J impact energy under 32 bar prestress [14].

2. Material and Method

In this study, 12 wooden plate honeycomb sandwich composite materials of different thickness (10-30mm) and the same size (100x150mm) taken from the wing structure of the aerobatic aircraft were used. Epoxy with 1 % wt CNT was applied to the samples. The mixture was carried out by ultrasonication method. Nanocomposite materials with different properties were obtained by applying the mixture to wood plate surfaces. The samples were cured for 90 min at 80 °C. In order to determine the improvement in mechanical properties after curing, low speed impact tests at 5J energy level were applied and the results were compared with the graphics. MGS lamination LR285 epoxy resin and LH285 hardening agent, which are frequently used in the field of aviation, were preferred as matrix. The ratio of epoxy, hardener and CNT was determined to be 100:80:1.8 and 100:80:0.9 [14]. The properties of CNTs are as follows: outer diameter < 8 mm, inner diameter 2–5 nm, length range 10–30 µm, density 2.1 g/cm3, purity 95%.

2.1 Low velocity impact test

Low speed impact test was applied to determine some mechanical properties of the produced materials. With the weight drop tests, real-life damages can be reproduced and animated on the sample, where it can be exposed to impact loads at close percentage rates. In principle, it works on the principle of dropping a piece of weight with a certain weight onto the sample. According to the test result, the damage conditions in the sample are examined by force, time and displacement data. In this study, the vertical weight drop impact test device, which is located in Konya Technical University, was used. The device has the capacity to test at 5 J energy level and 1.2549 m/s impact speed and also has a 20.5 mm diameter spherical tip and weight 6.35 kg. Only the striker values after the first impact are taken into account in the graphics. The dimensions of the samples of different thickness were not changed, taking into account the instrument sample holder. As a result of the impact tests, force-time change, force-displacement (displacement) change and energy-time change graphs were drawn.

3. Experiment Results and Findings

When the force-time graphs at 5 J energy level are examined, it is seen that the contact force on the 10 mm thick wooden plate is more effective than the 30 mm thick plate. When the figures are examined, it is seen that the

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contact force, which changes depending on time, reveals similar behavior on both samples (Figure 1). It is concluded that at this level of energy, the contact force acting on the surface decreases as the core height is increased. It is seen that 30 mm thick wooden plate absorbs more energy at 5 J energy level, although it affects less impact energy.

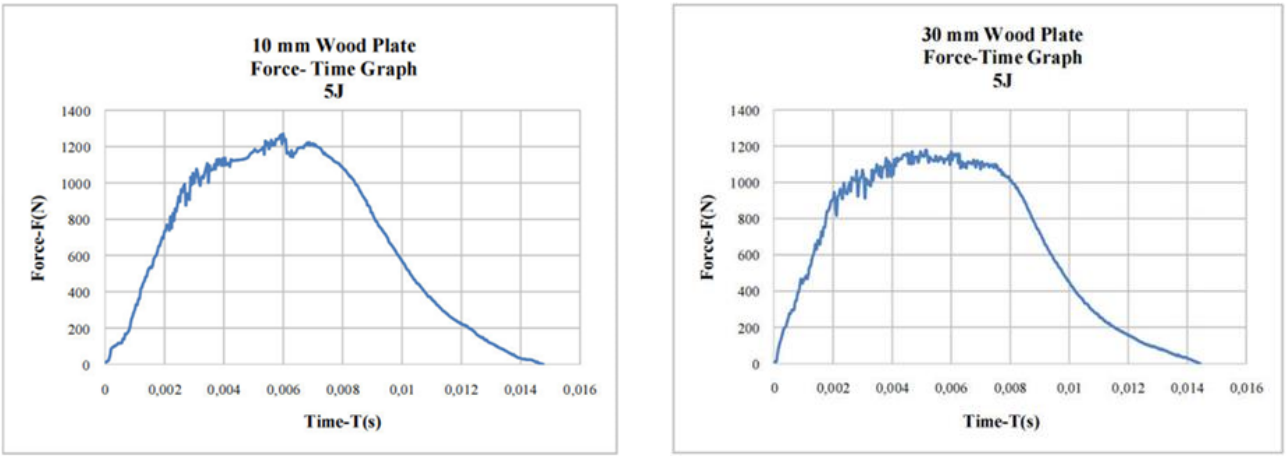

Fig. 1. Force-time graph for 5 J impact energy of a wood-plated sandwich panel with a plate thickness of 10-30 mm

According to the force-displacement graphs, a closed curve graph was formed depending on the penetration in both wooden plates with different thicknesses (in Figure 2). The small impact energy caused the force–displacement data to be closed curves. At this energy level, it is understood from the graph that cracking occurs on both wooden board surfaces, no collapse occurs and the load is covered by the core structure. However, it is seen that the sample with 10 mm thickness suffers more damage than the sample with 30 mm thickness. In the experiments, it was observed that no damage or destruction occurred on the lower surfaces of the plate at all impact energy levels.

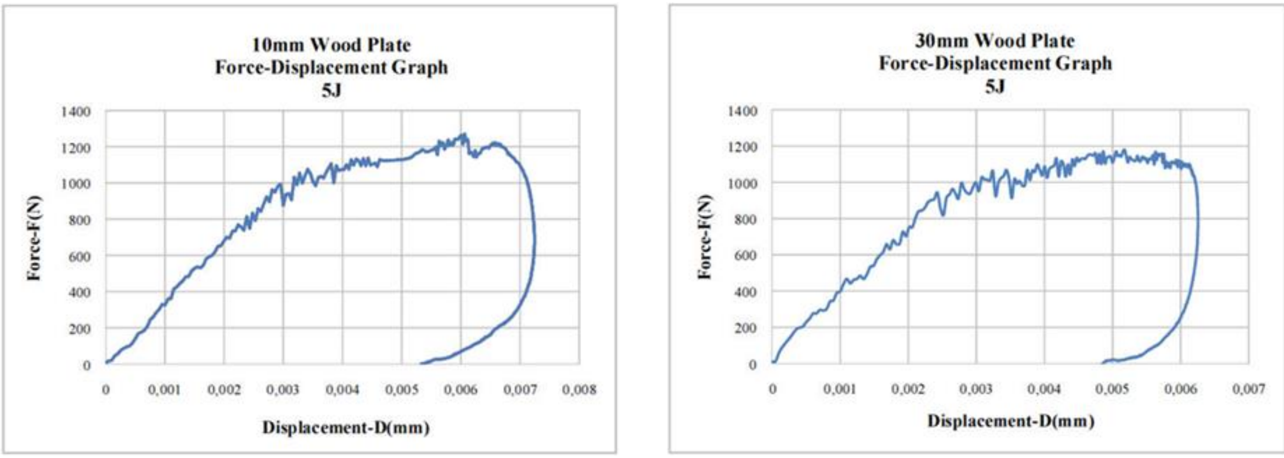

Fig. 2. Force–displacement plot for 5 J impact energy of a wood-plated sandwich panel with a plate thickness of 10-30 mm

In the energy-time graph of the 30 mm wood plate sample, most of the impact energy was absorbed mostly in the top layer and then in the core (in Figure 3). No rupture or puncture damage occurred in this area. In the other 10 mm thick composite, the data lines took a more downward course. It is understood from this graph that less energy

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is absorbed. In this case, part of the load was covered by the core structure and no tearing and separation damage occurred. At the same time, the highest impact energy occurred in the core structure with a thickness of 30 mm.

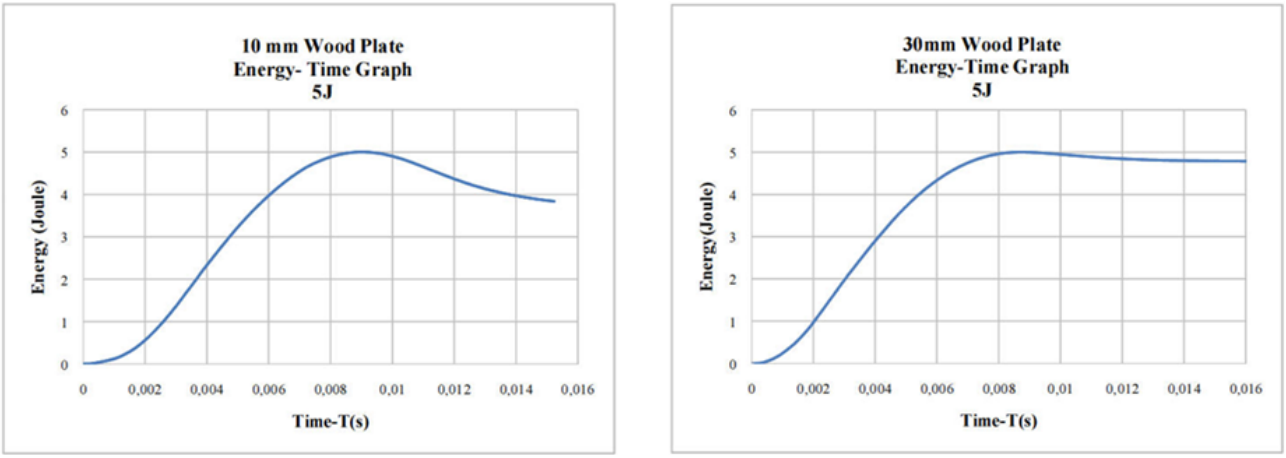

Fig. 3. Energy–time graph for 5 J impact energy of a wood-plated sandwich panel with a plate thickness of 10-30 mm

When the force-time graphs of the CNT reinforced plates at 5 J energy level are examined, the curve in the contact force in the 10 mm thick plate showed a fluctuating trend (in Figure 4). Here, the load firstly acted on the CNT matrix, the maximum contact force of around 1600 N was reached and only crack damage occurred on the plate surface. As CNT reinforcement increased the matrix strength, it reduced the negative effect of the load on the plates and honeycomb. In this way, not the all contact force could be absorbed and some of the force around 1450 N was transmitted to the lower wood plate surface and honeycomb core. No deformation occurred on the 30 mm thick plate surface. At 5 J energy level, the maximum contact force was resisted and all of the charge was absorbed on the CNT surface.

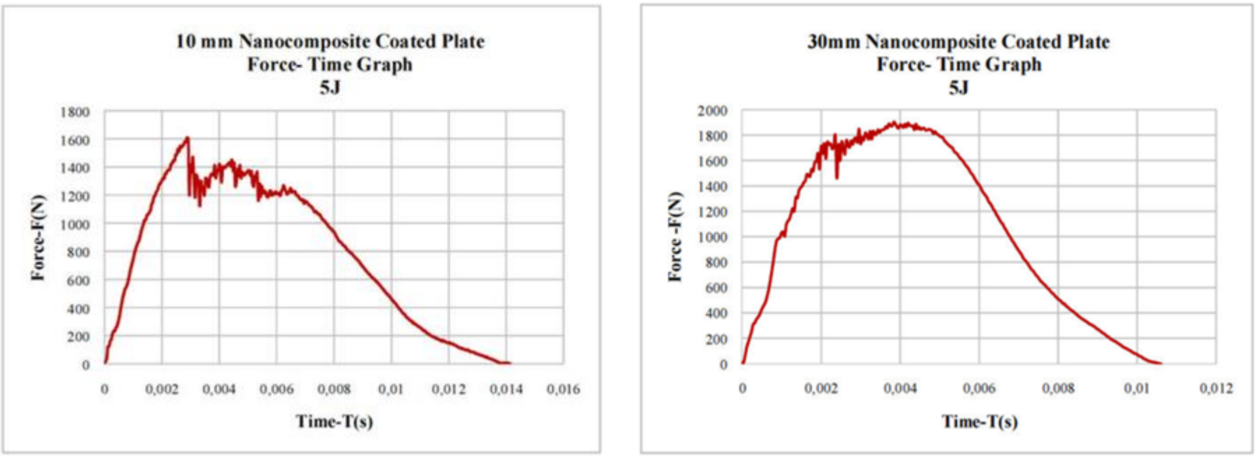

Fig. 4. Force-time graph for 5 J impact energy of a sandwich panel with a plate thickness of 10-30 mm

In the force-displacement graph of the 10 mm thick plate, it is seen that almost a closed curve is formed (in Figure 5). The reason for this is that it contains the section that first increases the load and then has a tendency to discharge, that is, the return section over the wooden plate. Here, it is seen that the damage reaches up to the wooden plate and precipitation occurs. In the 30 mm CNT coated plate, a wider curve was formed and the all load was covered by the outer surface. The highest contact force was measured here and there was no destruction or collapse on the outer surface after the impact.

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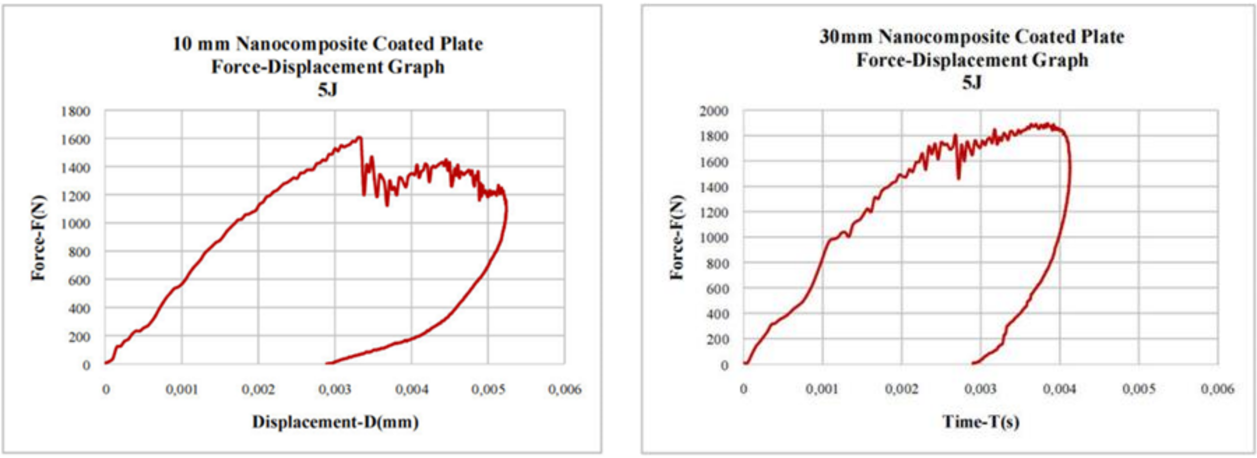

Fig. 5. Force-displacement graph for 5 J impact energy of sandwich panel with plate thickness of 10-30 mm.

As can be seen from the energy-time graph, the part of the impact load that could not be compensated was absorbed in the core at the same energy level in 10 mm thick plates (in Figure 6). It is also seen that no damage has occurred in the part of the core close to the lower layer. The absorbed energy was more in the 10 mm thick plate. However, the bounce energy of the striking tip from the sample was less than 30 mm, and the impact energy was absorbed in a shorter time (in Figure 7). In the 30 mm thick plate, all of the impact energy is absorbed in the upper layer. When compared with a wooden sample, the increase in core height in CNT coated composites is inversely proportional to the absorbed energy.

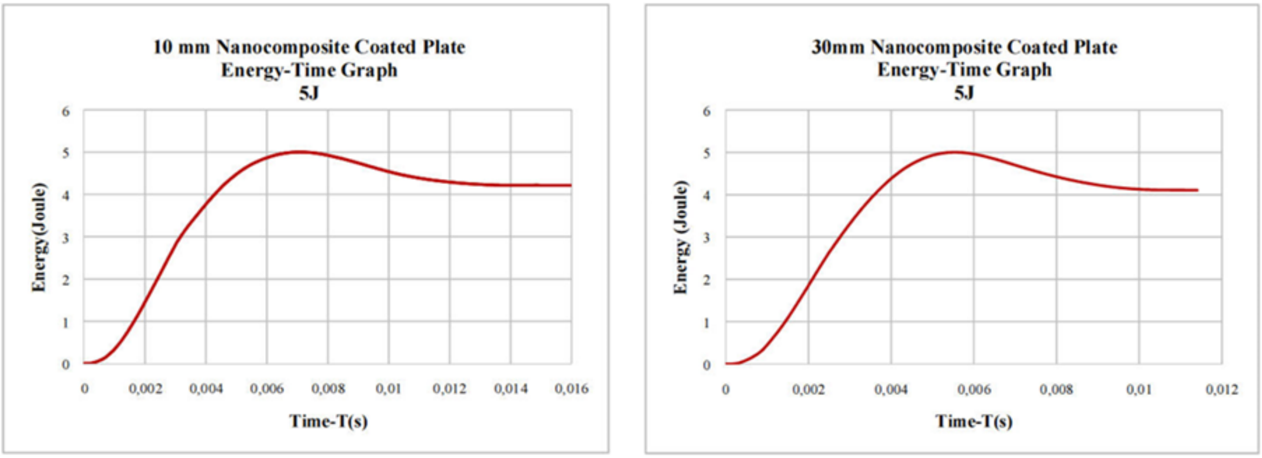

Fig. 6. Energy-time graph for 5 J impact energy of sandwich panel with plate thickness of 10-30 mm

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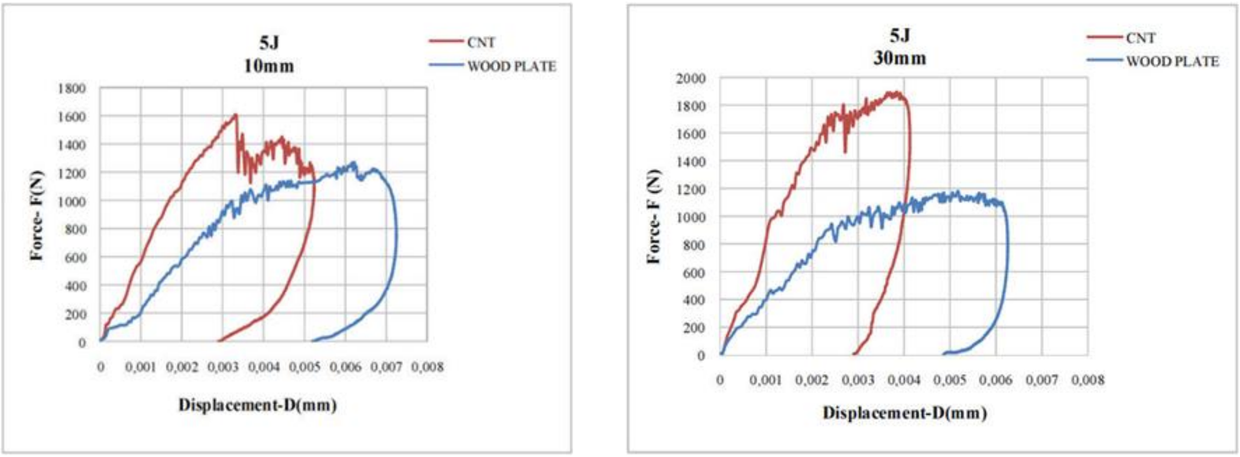

Fig. 7. Force-displacement graph of sandwich panel with plate thickness of 10-30 mm at 5 J energy level.

Table 1. Impact test response according to reinforcement condition and thickness difference

Type	Total Energy [J]	Velocity [m/s]	Peak Force [N]	Time [s]	Peak Displacement [mm]	Total Impuls [Ns]	Absorbed Energy [J]
10 mm Wooden	4.999	1.2549	1269.92	0.00632	0.0064	5113.11	4,3791
10 mm CNT	4.999	1.2549	1607.46	0.00320	0.0032	6228.99	4,2662
30 mm Wooden	4.999	1.2549	1178.61	0.00528	0.0046	4616.66	4,7890
30 mm CNT	4.999	1.2549	1903.50	0.00396	0.0037	5386.88	4,0790

4. Conclusion

Depending on the core height, increasing impact energy increased the contact force and displacement values. However, the increase in impact energy also increased the absorbed energy. Since the stretching rate of wood plate samples is high, their ability to absorb energy is also high. It has been observed from the graphics that the absorbed energy is higher in wood plate samples. Depending on the increase in impact energy, the types of damage observed in the samples appeared as fracture, cracking and collapse. However, matrix cracking was also observed in CNT reinforced plates due to surface rigidity. In addition, the increase in the core height and the effect of the CNT coating at the 5 J energy level decreased the amount of permanent displacement on the material and the absorbed energy. Due to the brittleness of CNT reinforced materials under load, it caused differences in total impulse values (Table 1). The difference in this value under the same test conditions can be explained by the duration of the thrust force acting on the surface. Increasing the core height decreases the impulse values. According to the results; it has been revealed that CNT mixing ratios and production methods can improve the impact resistance of honeycomb materials.

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