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Original article

Finite element modeling of the breakage behavior of agricultural biomass pellets under different heights during handling and storage

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ABSTRACT

It is very important to determine the amount of mechanical damage to biomass pellets during handling, transportation, and storage. However, it is difficult to determine the amount of damage to biomass pellets caused by existing external forces. However, a useful method is the finite element methods, which can be used in different engineering fields to simulate the posture of the material under defined boundary conditions. In this research, a drop test simulation of biomass pellet samples was performed by using the finite element method. An experimental study (compressive test) was carried out to measure some mechanical properties of the sample and use the obtained data in the finite element method simulation. The stress–strain curve of different biomass pellets was determined. Yield strength, Poisson's ratio, ultimate strength and modulus of elasticity, and stress were identified. In the end, the maximum equivalent stress, highest contact force (generated normal force from target surface at impact), and shape of deformation of samples at impact were obtained from simulation results. The drop scenario was created with 25 steps after the impact site, and the FEM simulation was solved. The maximum stress value was 9.486 MPa, and the maximum generated force was 485.31 N. at step 8 of the FEM simulation. When the stress magnitudes were assessed, simulation outputs indicated that simulation stress values are inconsistent with experimental data.

1. Introduction

As the population grows, the demand for energy has surged, forcing us to pay more attention to the reuse of agricultural waste such as crops straw and sawdust. The most direct and simple way to use the energy in crop residues is to compact loose materials into regular shapes, higher density and higher strength pellets (or briquettes). The dense biomass particles can be used for household cooking, heating and power generation. As an agricultural by-product, crop stalks and sawdust do not occupy any additional land. In addition, the carbon dioxide released during the combustion of crop residues pellets is offset by the amount of carbon dioxide absorbed during crop growth. Therefore, crop straw is a potential biomass material for pelleting. The density of the pellets is very high.

They are easier to handle than other densified biomass products because the grain processing infrastructure is used for pellets. The pellets are formed by an extrusion process using a cylindrical press, in which finely ground biomass material is constrained and cut to the required length by a square or circular cross-section die. The standard shape of biomass pellets is a cylinder with a diameter of approximately 7 mm and a length of less than 38 mm. Although the shape is uniform, the pellets are easily damaged through handling. Different grades of pellets have different energy and ash content. The safe transportation and effective processing of biomass

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pellets is very important for bioenergy applications (Tumuluru et al., 2011).

The safety of pellets during transportation and fuel handling is the key to determining standardized products for processing (Obernberger, 2010). Between manufacture and use, the pellets must not be physically damaged. This can minimize transportation costs and reduce the risk of fire caused by dust explosions (Hedlund et al., 2014). There have been many studies on the chemical properties of biomass (Vassilev et al., 2010). However, there is a shortage on studies cover the mechanical compressive strength of commercially produced biomass pellets (Graham et al., 2016). Graham et al. (2017); Shang et al. (2012) reported that the storage, transportation and milling processes of bioenergy are even more different. This study investigated the durability of biomass pellets for bioenergy applications and the applicability of quasi-static and dynamic mechanical strength testing.

Mechanical impact is one of the most important causes of product loss during transportation and trading operations. Damage caused during these operations may not immediately appear on the product, but will appear in the long term and reduce product quality in a short time. Damage caused by mechanical impact occurs if the external force acting on the product is greater than the breaking stress of the material. As is known, there are two types of loads, dynamic loads and static loads. Dynamic loads are more impactful to the product than static loads. The predicted deformation of products and the distribution of stresses and strains within them are among the most important issues in post-product processes, especially in transportation and trading operations.

Several previous experimental and mathematical studies have been conducted on various methods to study the quantity and distribution of stresses within different products and to determine their durability. One of the most important and often used mathematical methods in solving the most complex engineering problems is the finite element method (FEM). FEM is a numerical method for solving difficult or large-scale engineering issues including stress analysis, heat transfere, electromagnetism, and fluid flow. Since the 1950 s, the approach has been developed, and researchers have begun to apply FEM to additional engineering disciplines in the 1960 s (Moaveni, 2015). Pre-processing, computation, and post-processing are the three blocks that make up FEM. Pre-processing often entails splitting the object into a mesh of finite elements, defining boundary conditions, contacts, and the properties of the materials that make up the object or objects, as well as the external loads and beginning circumstances. The calculating process, which involves many differential equations at each element and node, is the next stage. The method's final phase is post-processing, which entails selecting and presenting relevant results for the problem analysis in a friendly and usable manner (Ayuga, 2015).

Xu et al. (2018) analyzed the equivalent stress and deformation during biomass material compression molding. They found that the stress distribution on the compressor is not completely uniform, and the stress at the base is slightly reduced. The stress and strain of the compression bar are the largest, and the stress concentration may appear on the top of the compression bar, which runs counter to the service life of the compression bar. Although there is a slight difference between the upper and lower parts, the overall deformation of the main mold is small. The overall change is not obvious, but the stress difference between the upper and lower parts of the main mold is very large, reaching 10 times. The stress and strain on the base are circularly reduced, but there is still stress concentration in the ledge, which is related to the service life. The contact stress distribution is uneven. Salema and Afzal, (2015) used finite element analysis to predict with multi-mode microwave system the heating behavior of bed and pelletized empty fruit bunch (EFB) biomass, and provides a framework and required model boundaries to predict the temperature and proper loading of specific microwave geometry material loading cavity.

In addition, this model can be effectively used to identify high and low temperature locations in biomass materials during microwave heating, thereby helping to design and optimize microwave applicators in terms of heating uniformity. The proposed model can also be used to determine the electromagnetic field distribution in the cavity (Teixeira et al., 2009). The computational fluid dynamics model implemented by using the FLUENT code describes in detail the combustion in the 15 kW pellet boiler. The results of this research allowed the optimization of the combustion chamber design and effective fine-tuning of the pellet boiler at various power levels (Tu et al., 2012). The finite element analysis software ADAMS/View module was used to establish the virtual design and simulation of the biomass flat mold press. According to this analysis, a dynamic characteristic model of the biomass briquetting machine that can provide a theoretical basis for the design of related equipment is obtained. With all these studies, however, to date, there is no research study on impact testing of compressed biomass pellets products, and because the difficult of testing it actually so this study was intended to understand the behavior of compressed biomass pellets deformation and to identify the distribution of stresses within the product under a different number of impact testing scenarios using the finite elements method.

2. Materials and methods

In this study, three different types of biomass pellets are used. Those pellets are made from sunflower residue, saw dust, and mixed residues (50% sunflower residue + 50% saw dust). These products were obtained from a local coal production factory in Belbis district, El-Sharkia governorate, Egypt. All experiments were conducted at the Faculty of Engineering Laboratories, Zagazig University, in 2019/2020. Tests were conducted in two steps.

2.1. Experimental Tests:

2.1.1. Determination of the physical properties of biomass pellet:

Through these tests the physical and mechanical properties of the biomass pellets samples were estimated as shown in (Table 1), and the samples were categorized into three groups as sunflowers, saw dust and mixed pellets based on the type of material from which the biomass pellets are made. The physical properties of biomass pellets were determined by the following methods: a vernier caliper with a sensitivity of 0.01 mm was used to measure length (L) and diameter (D). a digital balance (Model: AND-GF-6100, Bradford, MA, USA) with the accuracy of 0.01 g used to determine the pellets mass (M). pellets density was determined using the liquid displacement method according to ASTM, (2014).

2.1.2. Determination of the mechanical properties of biomass pellet

The compressive strength which determines how briquettes can be handled is a criterion of briquette durability (Jamradloedluk and Wiriyaumpaiwong, 2007). A briquette sample with good compressive strength can easily be transported, packed,

Table 1
physical properties of biomass pellets.

Biomass pellet	Sunflower	Saw dust	Mixed
Length, mm	14.2 ± 4.3	17.4 ± 4.8	21.1 ± 7
Diameter, mm	8.6 ± 0.4	8.4 ± 0.1	8.4 ± 0.2
Density, kg/m3	711	800	760
Biomass pellet	Sunflower	Saw dust	Mixed

or handled (Prasityousil and Muenjina, 2013). The Instron Universal Testing Machine (UTM) model (Norwood, MA, USA). with 5000 N load capacity using a compression test in accordance to ASTM, (2008) to determine the modulus of elasticity of pellets (Kers et al., 2010). The test was performed by placing a pellet between the horizontal metal plates of the machine. At loading speed of 0.5 mm min^{-1} compression test was carried for each pellets type. The average of elasticity modulus for sunflowers, saw dust and mixed pellets has been determined at two different positions (diametric and axial).

2.2. Three-dimensional solid modeling of the pellets:

In this study, SOLID WORKS, Version: 2016, commercial FEM software, was used for simulating the biomass pellets dropping test. After modeling a three-dimensional pellet shape in the software, the pellets were set as a rigid body which impact with the lower contact surface. The contact surface was set as a rigid body and once more as a flexible body (beech wood). Physical and mechanical specification of flexible contact surface have been presented in Table 2.

Table 2
Physical and mechanical properties of contact surface.

Contact surface	Flexible
Normal stiffness, (N/mm)/m2	595,000,000,000
Tangential stiffness, (N/mm)/m2	183,500,000,000
Mass density, kg/m3	640
Target thickness, mm	20

2.3. Scenario of the biomass pellets dropping case:

A drop test is a method of determining the impact of a part or assembly on a stiff or flexible surface like as the drop of something on the ground. In this study, the principle of the finite elements method was used to simulate the drop of biomass pellets by solid Works Program. The finite element method automatically calculates the load of both gravity and the impact on the assuming that there are no other loads restraints the movement during the dropping. Then the FEM calculates the velocity at the moment of impact from the following equation.

$$v = \sqrt{2gh} \tag{1}$$

where, g is gravity [m s^{-2}] and h is drop height [m]. The finite element method solves dynamic problems such as falling objects as a function in time. To simulate the drop of an object on a target surface, the finite element method code iteratively resolves the following equation because the forces and stiffness keep changing.

$$[M]a + [C]v + [K]x = F\text{..} \tag{2}$$

Where, M = mass matrix, C = damping matrix, K = stiffness matrix, F = external force vector, a = acceleration vector, v = velocity vector, x = displacement vector.

In this simulation, pellets move toward gravity as a rigid object until it impact with the target, considering that there is no rotational motion until the impact occurs. In the drop test, energy was lost owing to damping, friction, and plastic deformation. The FEM algorithm, on the other hand, does not provide damping in a drop test analysis. In this study, the biomass pellets were considered a linear isotropic material and friction has not been deter-

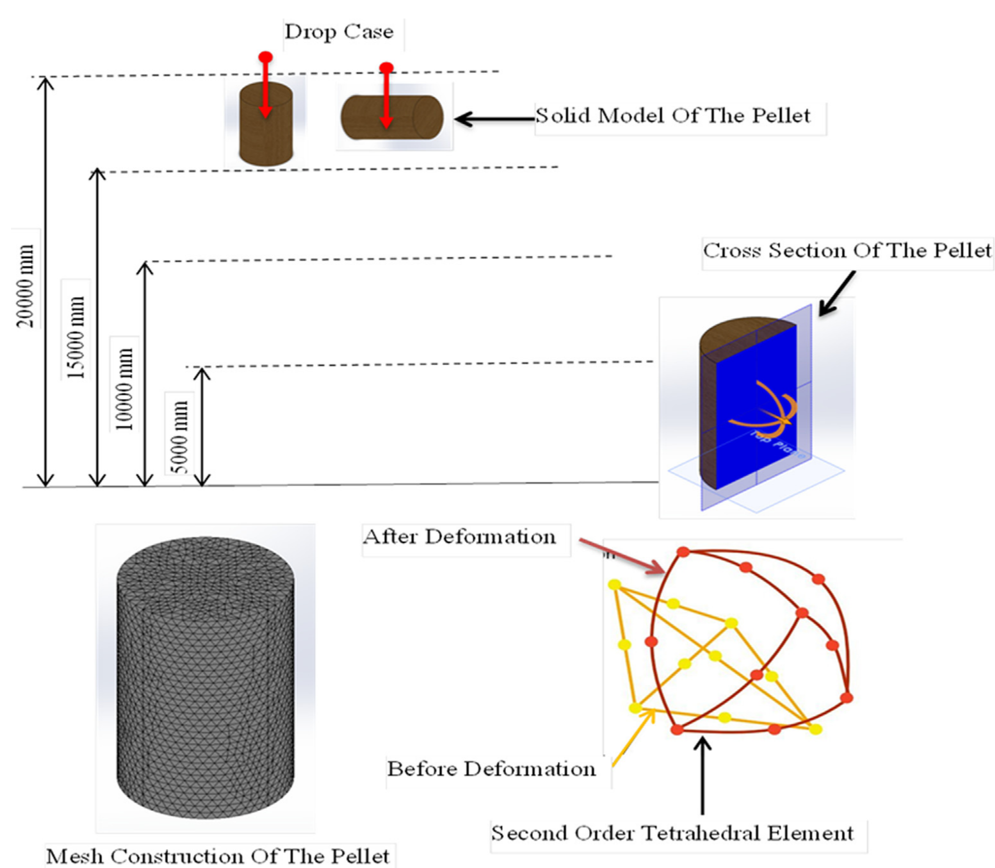

Fig. 1. 3D solid modelling, mesh construction and drop cases of biomass pellet.

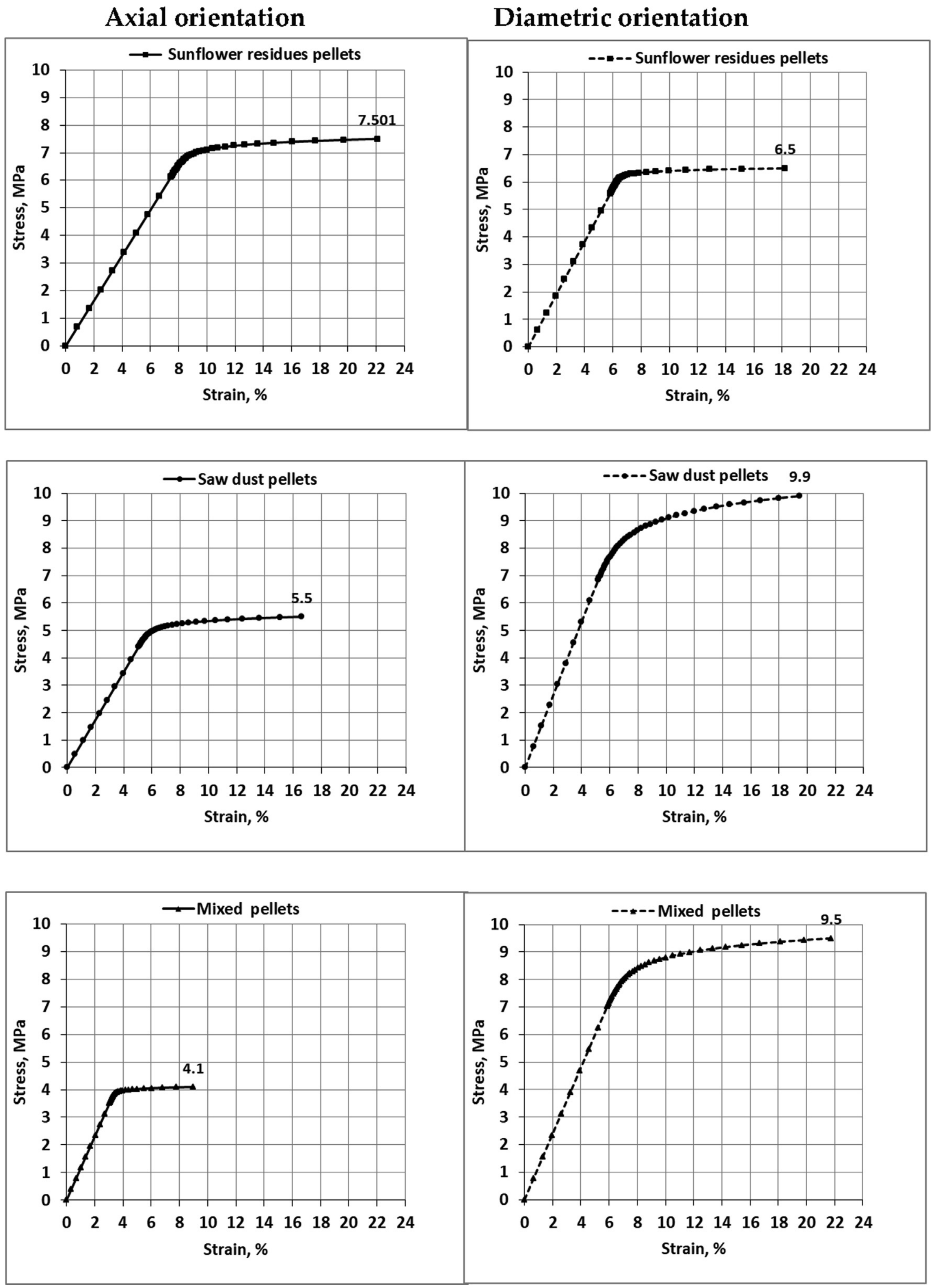

Fig. 2. The relationship between compressive stress and strain for different biomass pellets at axial and diametric orientations.

mined. Therefore, according to the previous equation, the impact does not result in any energy loss, and the model remains bounced off the target surface indefinitely. Solid work software uses a dynamic analysis solver in this test, which solves the problem using the explicit method of time integration. This was because of the effects of strain rates are maximum. This method is computationally intensive but numerically stable in dynamic problem analysis

The purpose of this study was to determine the deformation behavior of the pellets in the drop test. To attain this purpose,

Table 3
The results of pellets dropping test onto rigid surface.

Pellets residual type	Pellet orientation (deg)	Dropping height (mm)	Maximum stress (MPa)		Difference(MPa)
			Predicted	Ultimate	
Sunflower residues pellets	**0**	5000	6.309	6.5	0.191
		10,000	6.52	6.5	−0.02
		15,000	6.675	6.5	−0.175
		20,000	6.808	6.5	−0.308
	90	5000	6.653	7.5	0.847
		10,000	7.206	7.5	0.294
		15,000	7.363	7.5	0.137
		20,000	7.752	7.5	−0.252
Saw dust pellets	**0**	5000	8.327	9.9	1.573
		10,000	9.178	9.9	0.722
		15,000	9.819	9.9	0.081
		20,000	10.321	9.9	−0.421
	90	5000	5.048	5.5	0.452
		10,000	5.411	5.5	0.089
		15,000	5.893	5.5	−0.393
		20,000	6.51	5.5	−1.01
Mixed pellets	**0**	5000	8.029	9.5	1.471
		10,000	8.645	9.5	0.855
		15,000	9.142	9.5	0.358
		20,000	9.486	9.5	0.014
	90	5000	4.181	4.1	−0.081
		10,000	4.543	4.1	−0.443
		15,000	5	4.1	−0.9
		20,000	5.332	4.1	−1.232

Table 4
The results of pellets dropping test onto flexible surface (Beech wood).

Pellets residual type	Pellet orientation (deg)	Dropping height (mm)	Maximum stress (MPa)		Difference (MPa)
			Predicted	Ultimate	
Sunflower residues pellets	**0**	5000	5.785	6.5	0.715
		10,000	6.283	6.5	0.217
		15,000	6.353	6.5	0.147
		20,000	6.726	6.5	−0.226
	90	5000	7.071	7.5	0.429
		10,000	8.105	7.5	−0.605
		15,000	8.903	7.5	−1.403
		20,000	9.743	7.5	−2.243
Saw dust pellets	**0**	5000	8.091	9.9	1.809
		10,000	8.507	9.9	1.393
		15,000	8.926	9.9	0.974
		20,000	9.854	9.9	0.046
	90	5000	5.742	5.5	−0.242
		10,000	6.627	5.5	−1.127
		15,000	7.321	5.5	−1.821
		20,000	7.867	5.5	−2.367
Mixed pellets	**0**	5000	7.589	9.5	1.911
		10,000	8.118	9.5	1.382
		15,000	8.475	9.5	1.025
		20,000	9.011	9.5	0.489
	90	5000	4.861	4.1	−0.761
		10,000	5.569	4.1	−1.469
		15,000	6.107	4.1	−2.007
		20,000	6.509	4.1	−2.409

FEM simulations were used. During transportation and handling operations from producer to consumer or filling in silos, the potential drop heights ranged from 5 m to 20 m. Hence, Under the gravity of the earth, the pellets were dropped from four different heights of 5, 10, 15, and 20 m onto a stiff and flexible target surface. Because it was difficult to determine which orientation the pellets were falling, it had been allowed to fall in two different orientations (Axial and diametric) and the simulation was carried out according to the previously specified impact orientation of the pellets. For the drop test, 25 simulation steps were selected after the first impact moment. After the drop test simulation is completed, a video of the simulated drop test was recorded. Mesh structure was generated with a total of 56,665 elements and 67,516 nodes in the SolidWorks Simulation FEM code. The mesh structure was created using a second order tetrahedral solid element mesh type. The drop case scenario and pellet mesh construction are represented in Fig. 1.

3. Results

3.1. Mechanical properties of biomass pellets

Compressive strength of sunflower residues, saw dust and mixed pellets was measured in axial and diametric orientations. Yield strength, elasticity modulus and ultimate stress of different biomass pellets were calculated at two orientations. Fig. 2 shows the stress strain curve for sunflower residues, saw dust and mixed

Table 5
The results of pellets dropping test onto rigid and flexible surface.

Pellets residual type	Pellet orientation (deg)	Dropping height (mm)	Contact force (N)		Max.res. displacement (mm)	
			Rigid	Flexible	Rigid	Flexible
Sunflower residues pellets	**0**	5000	227.02	134.07	0.308	0.564
		10,000	312.21	203.94	0.428	0.759
		15,000	365.98	259.34	0.524	0.900
		20,000	406.16	296.31	0.609	1.041
	90	5000	222.22	154.69	0.411	0.486
		10,000	315.29	220.16	0.580	0.685
		15,000	386.27	269.58	0.710	0.837
		20,000	451.49	310.18	0.821	0.965
Saw dust pellets	**0**	5000	263.56	144.99	0.338	0.514
		10,000	368.53	207.24	0.455	0.717
		15,000	442.41	260.33	0.520	0.846
		20,000	496.70	306.85	0.576	0.954
	90	5000	225.01	152.04	0.378	0.473
		10,000	278.74	211.53	0.535	0.667
		15,000	318.92	254.96	0.657	0.816
		20,000	363.72	294.03	0.764	0.941
Mixed pellets	**0**	5000	253.37	140.29	0.322	0.524
		10,000	356.19	204.22	0.437	0.727
		15,000	430.19	258.80	0.496	0.864
		20,000	485.31	307.54	0.536	0.977
	90	5000	239.32	154.39	0.331	0.428
		10,000	291.63	210.37	0.474	0.606
		15,000	328.41	246.92	0.591	0.744
		20,000	351.51	277.34	0.698	0.864

pellets at axial and diametric orientations. The obtained results cleared that the yield strength was 6.2, 7.6 and 7.8 MPa at diametric orientation and 6.8, 4.9 and 3.91 MPa at axial orientation for sunflower residues, saw dust and mixed pellets respectively. And also, the modulus of elasticity was 96, 133 and 120 MPa at diametric orientation and 82, 87 and 115 MPa at axial orientation for sunflower residues, saw dust and mixed pellets respectively. While the ultimate strength was 6.5, 9.9 and 9.5 MPa at diametric orientation and 7.5, 5.5 and 4.1 MPa at axial orientation for sunflower residues, saw dust and mixed pellets, respectively.

3.2. Determination of the difference between predicted and experimental stress of biomass pellets:

After completing the FEM preprocessing program operation, the solution operation is generated. For each step, the deformation behavior of the biomass pellets, equivalent stress distribution and the resultant force from the rigid/flexible plane during impact (contact force) are obtained. The ultimate and maximum predicted stress of the biomass pellets considering the three types of pellets (sunflower residues, saw dust and mixed), different heights (5000, 10000, 15,000 and 20000 mm), Tables 3 and 4 list various pellet orientations (horizontal and vertical) and two contact surfaces (rigid and flexible). The table also lists the predicted differences in pellets stress. The horizontal and vertical directions in the table are written as 0 and 90° respectively.

According to Tables 3 and 4, at horizontal orientation (0°) the maximum predicted stress of the saw dust pellets was higher than that of the mixed pellets. Accordingly, sunflower residues pellet has the lowest value of maximum stress. But, at vertical orientation (90°) the highest and lowest values of maximum stress were recorded inside the sunflower residues and mixed pellets respectively. This was due to increasing the measured ultimate stress values. The maximum predicted stress occurred at a dropping height of 20,000 mm. As the drop height decreases, the stress is expected to decrease. Obviously, reducing the drop height will reduce the impact energy. Comparing the different contact surfaces in Table 3 and Table 4, the projected area obtained at 0° (horizontal) is higher than the projected area oriented at 90° (vertical). When a pellet falls, for example, when it falls in a 60° direction, weight force has two components. Compared with the total value of the force, the weight component in the falling direction has a lower value, and therefore, the strength of the impact was reduced compared with the impact from the 0° direction. Also, when the pellet falls in the vertical direction (90° direction) the value of the projected area is low. Since the falling path and the direction of weight force were the same.

3.3. Determination of contact force and maximum resultant displacement of different biomass pellets:

The effect of residual type of pellets with the dropping height on contact force under two pellet orientations of horizontal (0°) and vertical (90°) was studied on rigid and flexible surface. Results showed that an increase of dropping height was accompanied with increase in the contact force due to the increase in impact energy, and thereby increase in contact force. At rigid surface as shown in Table 5, the contact force was ranged from 225.01 to 363.72 N through the increasing of dropping height from 5000 to 20000 mm under the condition of vertical (90°) orientation with saw dust pellets. With respect to the variation of contact force under different residual type of pellets, results showed that the lowest value of contact force was recorded by using the saw dust pellets. Contact force values were 222.22, 225.01 and 239.32 N at vertical (90°) orientation under the three different pellets types of sunflower residues saw dust and mixed, respectively.

Respecting to beech wood as a flexible surface, obtained data as illustrated in Table 5 revealed that contact force values were 296.31, 306.85 and 307.54 N for horizontal (0°) orientation and 310.18, 294.03 and 277.34 N for vertical (90°) orientation under the dropping height of 20000 mm with using sunflower residues, saw dust and mixed pellets, respectively. Obtained data revealed that the dropping test at the horizontal (0°) orientation recorded contact force lower than that occurred at vertical (90°) orientation. Dropping test onto flexible target was less contact force than rigid target. Regarding to maximum resultant dis-

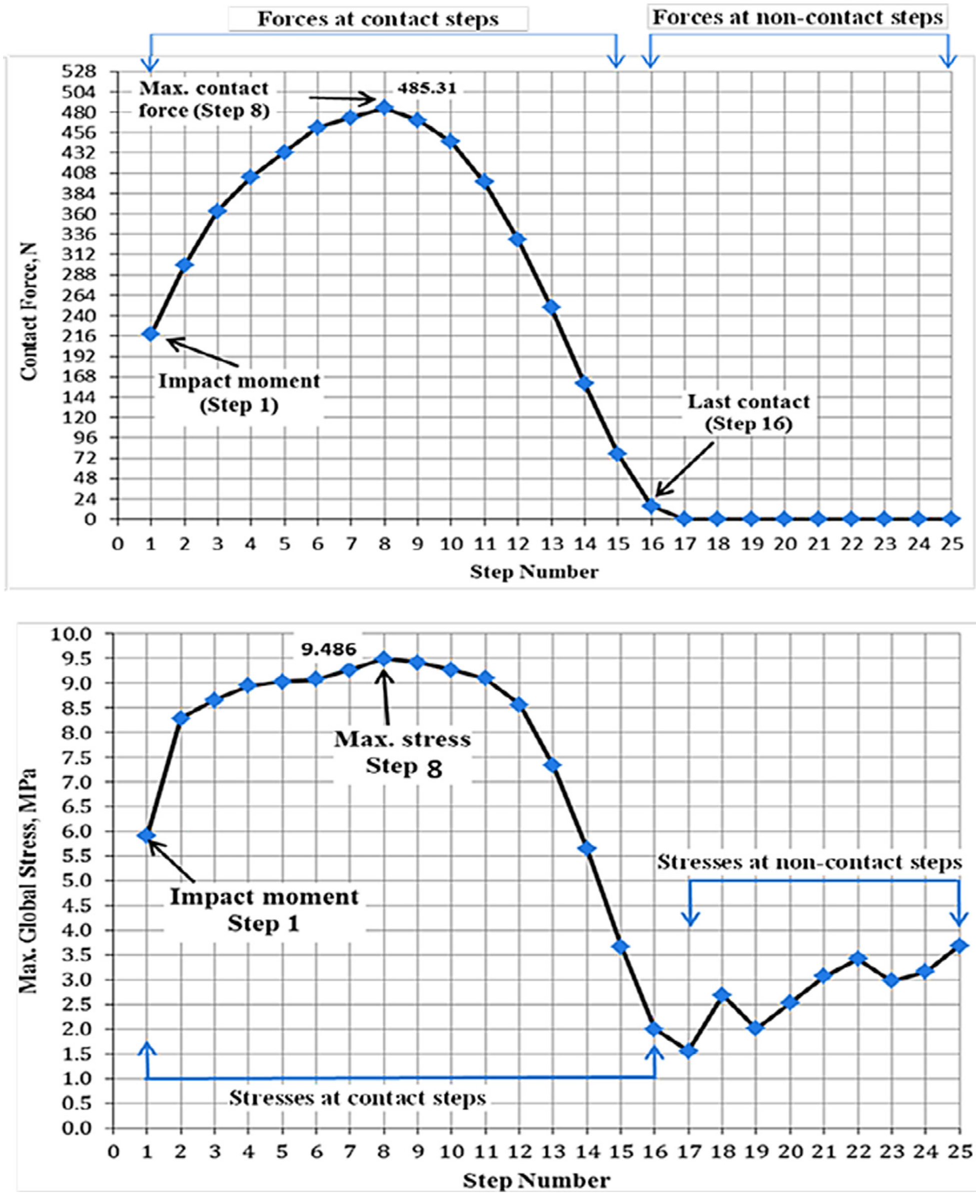

Fig. 3. Contact force and maximum stress of the mixed pellet under drop steps.

placement occurred in dropped pellets, as shown in Table 5 obtained results that carried out onto rigid surface indicated that the maximum resultant displacement was increased gradually by increasing the dropping height, due to the increase in impact energy. By dropping mixed pellets at vertical (90°) orientation, the resultant displacement was 0.331, 0.474, 0.591 and 0.698 mm for 5000, 10000, 15,000 and 20000 mm of dropping height, respectively.

Using mixed pellets gave the chance to reduce the resultant displacement compared to sunflower residues and saw dust pellets. At 20000 mm of dropping height, the resultant displacement was 0.609, 0.576 and 0.536 mm for horizontal (0°) orientation with using sunflower residues, saw dust and mixed pellets, in that order. Concerning the effect of different treatments by using flexible target as shown in Table 5, results clarified that resultant displacement occurred in sunflower residues pellets were 0.564, 0.759, 0.900 and 1.041% for horizontal (0°) orientation while 0.486, 0.685, 0.837 and 0.965% for vertical (90°) orientation under 5000, 10000, 15,000 and 20000 mm of dropping height.

3.4. Distribution of stress and contact force with respect to steps of time:

Equivalent stress distributions and contact forces were represented in Fig. 3 with respect to steps of time after impact as deformation behavior of the dropped pellets. Selected dropped mixed pellet onto rigid target from 20000 mm at horizontal (0°) orientation was taken as a model of deformation behavior for other experimental parameters. The results showed that the highest equivalent (von Mises) stress and contact force were 9.486 MPa and 485.31 N at steps 8. While, the lowest value of equivalent (von Mises) stress and contact force were 1.560 MPa and 0 N at steps 17.

The FEA results and experimental results in Fig. 1 were used to compare the approximate damage in pellets. As shown in Fig. 1, 7.8 MPa was the yield stress. The simulation result of 9.486 MPa is smaller than this figure. As a result, it’s safe to say that this drop case has pellet damage. Also, the obtained ultimate strength from experimental results was 9.5 MPa and this value was found

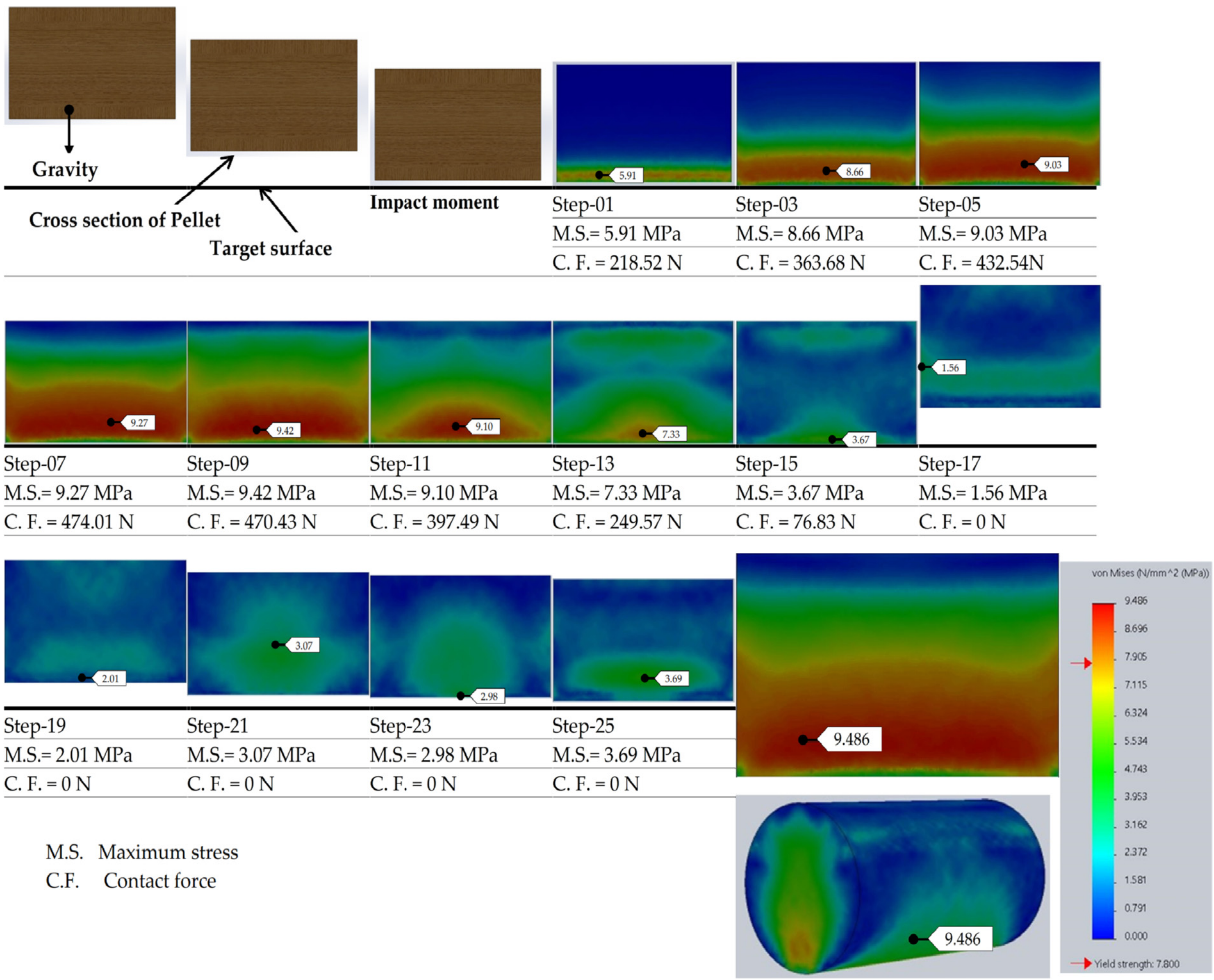

Fig. 4. A dropping test for a modelled mixed pellet in (0°) horizontal orientation dropped from 20000 mm on rigid target.

approximately equal the obtained value from simulation results. So, FEA results are valid.

4. Discussion:

It is obvious that the modulus of elasticity for all biomass pellets at diametric orientation was greater than that at axial orientation. As a consequence, the stiffness of biomass pellets at diametric orientation was greater than that at axial orientation. It was also observed that the yield strength of saw dust and mixed pellets at diametric orientation was greater than that at axial orientation but the opposite was noted with sunflower pellets. As for the ultimate strength, it was found to be following the same trend of the yield strength, these results are in agreement with Gilvari et al., (2020) and Larsson and Samuelsson (2017). The variation between three biomass pellets was due to the heterogeneous nature of biomass pellet composition (Williams, et al., 2018). It can be concluded that in most tests, the maximum predicted stress of the rigid surface is higher than that of the flexible (wood) surface, and that is because of the higher elasticity and the higher impact effect of the rigid surface.

According to Tables 3 and 4, the maximum predicted stress in saw dust and mixed pellets obtained with 90° (vertical) was higher than that for 0° (horizontal) orientation. This result is due to the ultimate stress with 90° (vertical) was higher than that for 0° (horizontal) orientation in addition to the area of the contact region and weight-force direction. The maximum weight force was acted on the contact area, but because the area of the projection region is the smallest, so the stress has highest value, these results are in agreement with Yousefi, et al., (2016). On the other hand, an adverse behavior was observed in sunflower residues pellets. Where, the highest value of maximum predicted stress was recorded at 0° (horizontal) orientation because of the ultimate stress for 0° (horizontal) was higher than that 90° (vertical). Results showed that an increase of dropping height was accompanied with increase in the contact force due to the increase in impact energy, and thereby increase in contact force. The maximum resultant displacement that carried out onto rigid surface was increased gradually by increasing the dropping height, due to the increase in impact energy. The maximum resultant displacement was noticed to be lower by using rigid than flexible target. It is due to higher elasticity of rigid surface and the increasing impact effect compared to the flexible target (wood) (Bradley, 2009; Oveisi, et al., 2013).

The results of the presented research are in agreement with the earlier research conducted by Caglayan, et al., (2018) according to the FEM simulation findings. Fig. 4 shows the stress levels, contact force values, and charts for the other phases. It can be seen from Fig. 4 that once the pellet hits the rigid target; the first stress value appears at step 1. In step 8, the contact force hits its peak, and the pellet begins to bounce in response to a stiff target. Meanwhile, the maximum stress is attained at step 8. Because there is no contact with the stiff target in step 17, the contact force is zero. However, even if there is no contact force at all after step 17, the stress range of 1.560:3.689 MPa can be observed.

5. Conclusion

The findings of this research add to our knowledge of the failure / deformation of biomass pellets through the use of computer-aided engineering applications. This study highlighted the use of finite element modeling to predict damage of biomass pellets. In this study, the ultimate strength of sunflower residues, sawdust and mixed pellets was determined experimentally and modeled by FEM. Different contact surfaces and pellet orientations are also considered. The ultimate strength of sun flower residues, saw dust and mixed pellets were 6.5, 9.9 and 9.5 MPa for diametric orientation and were 7.5, 5.5 and 4.1 MPa for axial orientation. The lowest (more damage) and the highest (more durability) differences between the predicted and experimental stress were −2.409 and 1.911 MPa respectively. These values were related to the vertical drop of the mixed pellets from a height of 20,000 mm onto the flexible surface and the horizontal drop of the sawdust pellets from a height of 5000 mm onto the wood surface. The results of these studies can be used to predict the damage characteristics of dropped biomass pellets as well as to estimate the critical drop height for testing purposes.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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