

Modeling and Simulation of Straw Collector using Finite Element Method

Mana Tiraroj, Kiatfa Tangchaichit and Jarupol Suriyawanakul*

Department of Mechanical Engineering, Faculty of Engineering, Khon Kaen University,
123 Moo 16, Mittraphap Road, Nai Muang, Muang, Khon Kaen, 40002, Thailand
(*corresponding author)

mana.tiraroj@kkumail.com, kiatfa@kku.ac.th and jarupol@kku.ac.th*

Abstract. *The aim of this paper is to determine a suitable structural size of a straw collector. Modeling, simulation and diagnosis were done by using the SolidWorks software. The test was operated in the environment of KhonKaen province which has the maximum soil stress of 240 kPa at the moisture content of 2 percent (the worst condition). The optimum design was done by varying the size of round bars and thickness of equal angle steels in the rake part. The result was defined by operating the finite element method while performing the SolidWorks Simulation. The appropriate size of the round bar and equal angle steel was found to be 10 mm for the diameter of round bars and 3 mm for the thickness of equal angle steels.*

Received by	30 January 2020
Revised by	30 March 2020
Accepted by	27 April 2020

Keywords:

Straw bale, Straw collector, Rake, SolidWorks Simulation, Finite element method

1. Introduction

Rice straw [1] comes with the rice that farmers harvest and before the rice grains removed. Although rice straw is a form of waste from farming, it can be utilized in many areas such as animal feed, ethanol production, mushroom cultivation, sound absorption, heat protection materials and used as biomass fuel. Rice straw is classified into 3 types: hand-harvested straw, tractor-harvested straw, and hand- and tractor-harvested straw.

Years ago, cows and buffalos were used by farmers as labor for farming. Therefore, farmers stocked rice straw to feed their animals. Later on, when machines have replaced the animal labor, farmers burn their rice field [2] to prepare the field for the next crop because the remaining straw will be trapped in the tractor wheels, plow blades and tillers, making the work difficult. Burning is thus an easy way to clear the crop fields; however, there is a disadvantage from air pollution which negatively affects the ecosystem. Nowadays, there is a campaign for farmers to cut rice

stubbles [3] to reduce the cost of plowing, seeding, sowing, and fertilizers and to enable faster harvesting than the first seed sow planting. Moreover, there is research that supports stubble cutting to control root rot [4]. Afterward, people's support has been placed on increasing utilization of rice straws, such as using rice straws for mushroom cultivation, removal of sodium chloride in wastewater (5), using them as construction materials [6], [7], [8], transforming them into fuel for power plants [9], machine-compressing and storing rice straws in the form of straw bales. The machines used were of high horsepower and operated with a complex-system engine, and thus are expensive for farmers with low incomes to afford. Some Thai farmers therefore created a low-cost straw bale compressor to use by themselves [10]. However, their machine is not an automatic straw collection system. The disadvantage is in its requiring 2-3 persons to feed the straw into the machine and bind the straw manually. Thus, if there is an economical rice straw collection machine to supplement the process, work efficiency will be increased.

The objective of this research is to design a rice straw collector with a suitable structural size for reducing the problem of open field burning, increasing income of farmers and also using rice straws for further benefits.

2. Research Procedure

2.1 Data collection

From the study of machines with similar characteristics to a rice straw collector, it was found that the machine with such characteristics is mainly used to collect garbage and leaves on streets and lawn. It is the type that requires human and a tractor to operate. Mostly, it has been built with a sweeping system [11], [12], [13] and a raking system [14], [15].

In this study, the fields selected for the research were in Khon Kaen, where Thaowandee [16] found that the maximum compressive stress of Khon Kaen's soil in the fields were 238.61, 44.99 and 12.39 kPa and the moisture contents were 2.14, 4.1 and 6.8 percentage, respectively based on the Unconfined Compression testing.

2.2 Design

2.2.1 Define the Design Function

This device was designed by the research team so that farmers can install it on the engine of walking tractors that they have. The machine does not only reduce the expenditure on purchasing an engine and mechanism complexity but also reduces the labor costs and helps farmers work faster than working with only human labor. The research team defined the important function requirements in the design as follows.

No	Requirement
1	Safety
2	Application
3	Fuel Conservation
4	Durability
5	Convenience
6	Mobility
7	Cost
8	Maintenance
9	Efficiency

Table 1 Requirements of the straw collector’s design functions

2.2.2 Define the Specific Data

From the requirements of the straw collector’s design functions in Section 2.2.1, the following specifications of the collector were designated to meet the objective:

1. Useable with a walking tractor engine (8-14 horsepower)
2. Uncomplicated to install on a walking tractor
3. Having a low center of gravity
4. Able to store rice straw more than 1 cubic meter per cycle
5. Strong enough to use in the rice field.

2.2.3 Design the prototype

The prototype was designed based on the requirements and specifications in Sections 2.2.1 and 2.2.2. For a straw collector to be affordable by smallholder farmers, it must be compatible to use with their own walking tractor. The shape of this straw collector is designed according to usability to collect a rice straw that laid on the ground by raking along the fields and it has a seat for the operator to have comfort while working. Furthermore, it must have a safety factor greater than 2, based on the general recommendation of safety factor between 2-2.5 for use with regular materials in which the loading and environmental conditions are not severe [17].

The straw collector is composed of agricultural tires, semi-circular large rake, and seat. The rake set is installed at the front part of the seat and connected to the rake adjustment lever to allow the user to easily monitor and control the rake. The walking tractor will be attached to a driving tractor with a seat to drag the rake for sweeping rice straw on either side of the machine.

In this case, the weakest part to be analyzed was the rake set because this part receives the highest load and is also very delicate.

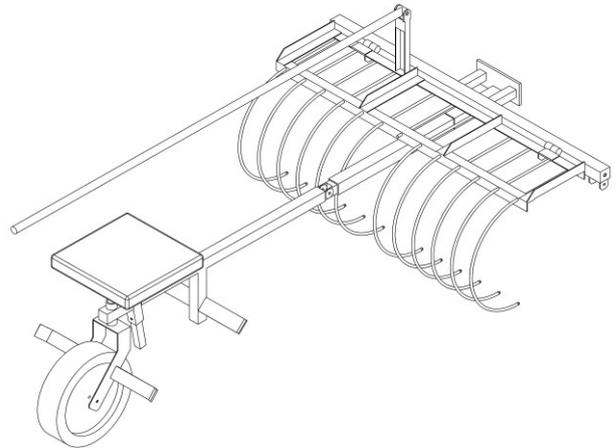


Fig. 1: Prototype design

2.3 Simulation

2.3.1 Materials

According to the purpose, material selection requires consideration of the following important things: strength, durability, economy, and rarity. Therefore, ASTM A36 structural steel [18] was chosen to use. It has the material properties as shown in Table 2.

	Value	Unit
Elastic modulus	200	GPa
Mass density	785	kg/m ³
Poisson ratio	0.26	-
Yield strength	250	MPa
Tensile strength	400	MPa

Table 2 The material properties of ASTM36 structural steel

2.3.2 Modeling

The straw collector model was created by the SolidWorks software, as shown in Fig. 2.



Fig. 2: Modeling of the straw collector

2.3.3 Finite element analysis

The strength, safety and durability of the structure are the first important thing to realize when creating a model. In order to meet the requirements as mentioned, standardized and effective methods were analyzed to determine the finite element method, which was in turn used to analyze the model by using SolidWorks Simulation.

2.3.4 Boundary conditions

The boundary conditions were set to fix the translations and rotations (All displacements and angular displacements were zero) at the back surface of the rack part as shown in Fig. 3.

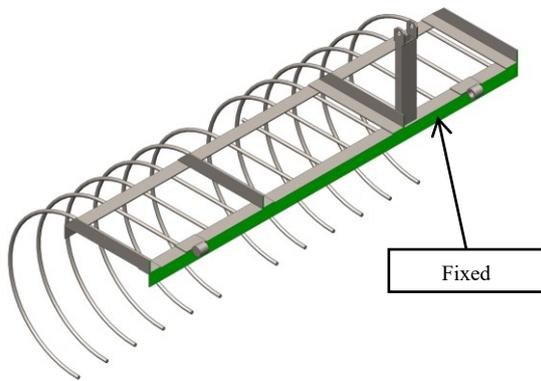


Fig. 3: Boundary condition

2.3.5 Loads

Since the research team wanted to create a model of the rice straw collector that is able to move through the rice field, the load was determined as stress which was equal to the stress of the soil with the minimum moisture content of 2 percent, equal to 204 kPa [16], and the acceleration due to the gravity of the earth was 9.81 m/s². It was placed at the end of the round bar and center of mass, respectively, as shown in Fig. 4.

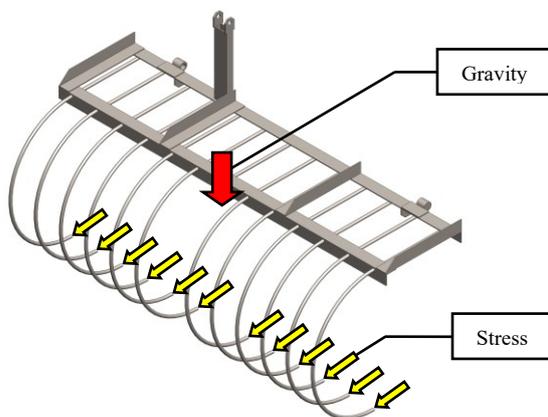


Fig. 4: Type and position of applied loads

2.3.6 Mesh

In the SolidWorks Simulation, the default options of mesh were assigned at 10 nodes to each solid element: four corner nodes and one node at the middle of each edge (a total of six mid-side nodes) [19] because it was focused on a round bar that was complicated geometry, it makes a solution inaccurate when using a hexahedral, prismatic or pyramidal elements, as shown in Fig. 5.

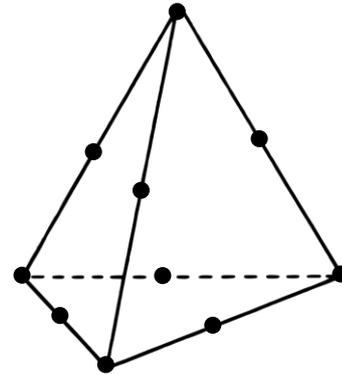


Fig. 5: Ten nodes tetrahedral element

After mesh independent study of each model, found the meshes had the average element size of 11.0494 mm, the average number of elements was 37084, and the average number of nodes was 80376.

2.3.7 Dimensions

With the initial size, the maximum von Mises stress occurred at the round bar (RB) which was the weakest part thus increasing the diameter continuously to gain its strength. It appeared that the maximum von Mises occurred at the equal angle steel (EA) instead because of the burden of an increasing size of the round bar (RB). According to the previous purpose requiring the gaining of the strength of the equal angle steel (EA), it was also necessary to increase its thickness. This was ongoing until the data shown in Tables 3 [20] and 4 [21] had been used completely. Then the yield stress was divided by the maximum von Mises stress from above to obtain the safety factor.

No.	Diameter of the round bar(mm)
1	6
2	8
3	9
4	10
5	12
6	15
7	19
8	22
9	25
10	28
11	34

Table 3 The diameter of round bar

No.	Thickness of the equal angle steel(mm)
1	40x40x3
2	40x40x4
3	40x40x5
4	40x40x6

Table 4 Thickness of the equal angle steel

2.3.8 Results

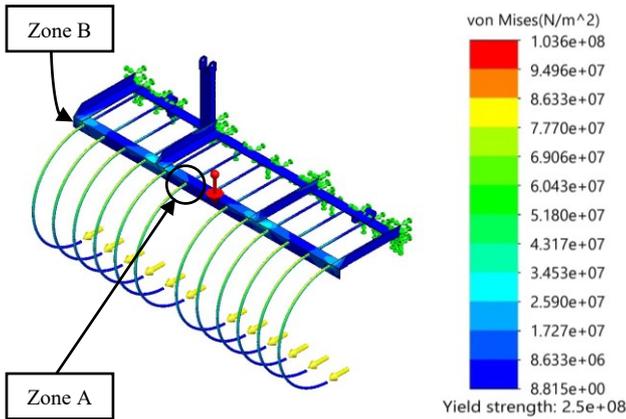


Fig. 6: Result of simulation by SolidWorks

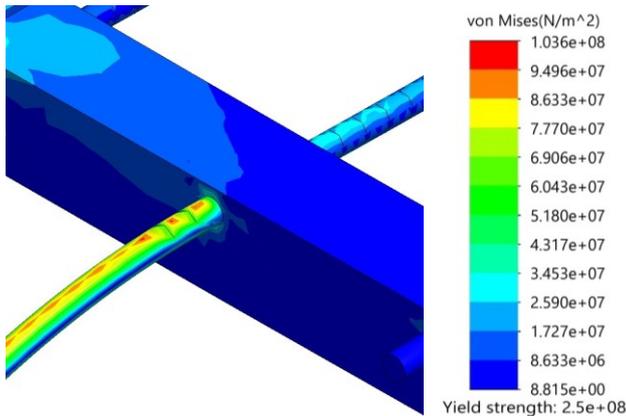


Fig. 7: Result of simulation at zone A

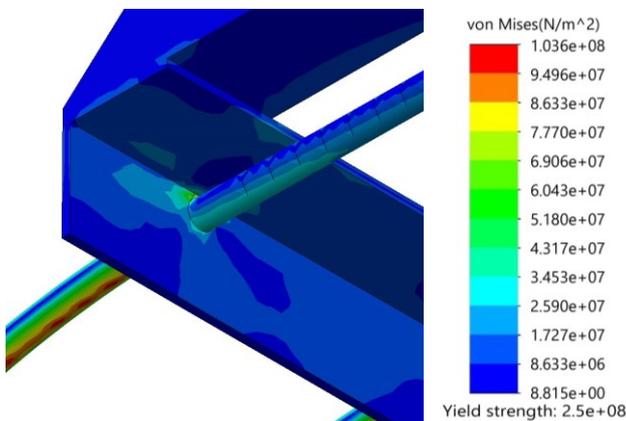


Fig. 8: Result of simulation at zone B

From the simulation, the results showed that the von Mises stress occurred at the round bar (RB) close to the welds (zone A) and inside corners of the equal angle steel (EA) (zone B) alternately. Also, the relation was shown between the diameter of the round bar (RB) and the equal angle steel (EA) that affected the von Mises stress and the safety factor as shown in Table 5.

Case	RB(mm)	EA(mm)	σ_{RB} (MPa)	σ_{EA} (MPa)	SF _{RB}	SF _{EA}
1	6	3	189	93.34	1.323	2.678
2	8	3	126.5	90.19	1.976	2.772
3	9	3	125.2	92.07	1.997	2.715
4	10	3	103.6	98.29	2.413	2.543
5	12	3	82.55	114.4	3.028	2.185
6	12	4	81.9	61.47	3.053	4.067
7	15	4	65.99	61.34	3.788	4.076
8	19	4	56.89	82.62	4.394	3.026
9	19	5	53.61	51.78	4.663	4.828
10	22	5	43.12	45.38	4.464	5.509
11	22	6	43.46	43.99	4.637	5.683

Table 5 The diameter of the round bar (RB) and thickness of the equal angle steel (EA) affected the relation between the von Mises stress and safety factor

2.4 Conclusion

The results showed that when the diameter of round bars increased, the von Mises stress of the round bar (σ_{RB}) reduced, affecting a rise of the safety factor of the round bar (SF_{RB}). However, this created more von Mises stress of the equal angle steel (σ_{EA}), causing the safety factor of the equal angle steel (SF_{EA}) to go in the opposite direction because the stronger round bar generated more load for the equal angle steel.

The recommend case is case No.4 because it's the least safety factor which was initiated by the maximum von Mises stress (The highest von Mises stress from the comparison between the round bar and the equal angle steel) of this case achieved the requirements as safety factor is greater than 2 (17). For the safety factors of more than 2 in other cases, the result is a waste of money due to overdesign.

Acknowledgements

The authors gratefully thank Faculty of Engineering, Khon Kaen University for supporting the SolidWorks software, Energy Policy and Planning Office (EPPO), Ministry of Energy for the funding, Nantiwat Pholdee and Woravut Suwanrueng for advice and information.

References

- [1] Tawatchai, S. (2015). Rice straw and benefit from itself. From: <http://www.puechkaset.com/>
- [2] The Pollution Control Department, Ministry of Natural Resources and Environment. Thai farmers join together not to burn rice straws. From: http://www.pcd.go.th/info_serv/air_straw.htm
- [3] Department of Agriculture Extension, Ministry of Agriculture and Cooperative. Rice cultivation by stubble cutting. From: http://www.thaismartfarmer.net/index.php/userservice/p_know_detail/show/105
- [4] Dobie, JB., Miller, GE., Mosley III, RH. (1984). Ground level harvest of rice straw. *Transactions of the ASAE*. 27(5):1263–9.
- [5] Maneechote, P., Choomjaihan, P. (2017). A study of removal potential of NaCl in synthetic wastewater Using Rice Straw. *Thai Society of Agricultural Engineering Journal*. 2:59–67.
- [6] Chaussinand, A., Scartezini, JL., Nik, V. (2015). Straw bale: a waste from agriculture, a new construction material for sustainable buildings. *Energy Procedia*. 78:297–302.
- [7] Seehabut, P., Wiangtai, P., Changyant, P., Thuanmunla, J. (2017). The usage of rice straw in interlocking block. *Journal of Science and Technology Mahasarakham University*. 36(4):478–85.
- [8] Inthata, S., Khankham, C. (2017). Use of rice straw to produce the insulation cement board. *Pawarun Agriculture Journal*. 12(1):25–34.
- [9] Suramaythangkoor, T., Gheewala, SH. (2010). Potential alternatives of heat and power technology application using rice straw in Thailand. *Applied Energy*. 87:128–33.
- [10] Nakwaitananukul, S., Chaisatapakorn, C., Opanukul, W., Mongkhonthanathat, J. (2009). Development of baler suitable used in Thailand. *Agricultural Machinery Testing and Development Group, Agricultural Engineering Research Institute, Department of Agriculture, Ministry of Agriculture and Cooperative*.
- [11] Cuiying, W., Rui, Z., Songsong, H. (2018). Road sweeper. CN107916643A.
- [12] Biao, L., Xianmin, Z., Jianghui, X., Hua, L., Guansheng, J. (2012). Vehicle for cleaning leaves of lawn. CN102007856A.
- [13] Hang, HL. (2016). Lawn sweeper. USD757123S1.
- [14] Banks, TE. (1986). *Straw raking device*. GB2162733A.
- [15] Mullins, HL. (1980). Mobile lawn rake attachment. US4312095A.
- [16] Thaowandee, P. (2019). A study of ultimate bearing capacity of Khon Kean loess. Master of Engineering Thesis, Civil Engineering, Graduate School, Khon Kaen University.
- [17] Engineering Toolbox. (2010). Factors of safety. From: https://www.engineeringtoolbox.com/factors-safety-fos-d_1624.html
- [18] ASTM International, West Conshohocken, PA. (2019). ASTM A36/A36M-19, Standard Specification for Carbon Structural Steel. From: www.astm.org.
- [19] Dassault Systemes. (2019). SolidWorks simulation - default options of mesh. From: https://help.solidworks.com/2019/english/SolidWorks/cworks/IDC_HELP_PREFERENCE_MESH.htm
- [20] Thai Industrial Standards Institute. (2016). TIS 20-2016. From: <https://www.tisi.go.th/data/standard/fulltext/TIS-20-2559p.pdf>
- [21] Thai Industrial Standards Institute. (2015). TIS 1227-2015. From: <https://www.tisi.go.th/data/standard/fulltext/TIS-1227-2558m.pdf>

Biographies



Mana Tiraroj was born in Sakonnakhon, Thailand, 1994. He received his bachelor's degree in Mechanical Engineering from Khon Kaen University, Thailand in 2017. Now he is the master's degree student in Mechanical Engineering, Faculty of Engineering in Khon Kaen University, Thailand.



Kiatfa Tangchaichit is an associate professor in Mechanical Engineering Department, Faculty of Engineering, Khon Kaen University, Thailand.



Jarapol Suriyawanakul is a lecturer in Mechanical Engineering Department, Faculty of Engineering, Khon Kaen University, Thailand.