DESIGN AND ANALYSIS OF A ROTAVATOR

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***Abstract**: A rotavator is used to plough the land by using a series of blades that cuts and pulverizes the soil in a single pass. This work is to present the design and analysis of a rotavator by using CAD software and ANSYS. The CAD software which is used in this study is Solidworks, a 3D modeling design program i.e., mostly used by the operators for its ease of use. During the part of the project, the dimensions of a rotavator are calculated by using design procedures. Using the values obtained from the calculations, a three-dimensional model of the rotavator is designed by using Solidworks. Then the 3D model is imported into ANSYS software. By providing required input i.e., force acting on each blade, the static structural and fatigue analysis of the rotavator was performed to get optimum results. The type of rotavator blade used in this present study is an L-shaped blade. The type of material used for this L-shaped blade is taken from reference i.e., High Carbon Steel. In addition to High Carbon steel, other materials like EN24 Steel, EN8 Steel, Boron Steel, and Chromium Steels were used. From the results, the best material suggested for a new design is boron steel. Finally, the present model is modeled and analyzed to a new design with a change in its radius of curvatures. The new radius of curvatures considered in the modified design is R24, R34, R38, and R40. From the results, it is observed that R38 gives lower deformation and considerably has higher fatigue life. In view of this boron steel with R38 is selected as the best design for the blade. With this new design, the failure of the rotavator blade may be decreased.*

***Keywords**:* Rotavator, Solidworks, ANSYS, Blade, Static Structural analysis, Fatigue analysis

1. INTRODUCTION

Farm machinery and/or implements are any sort of machinery or implements used in the agricultural production process. This machinery is frequently used for both agricultural and animal production. Farm machinery encompasses a variety of devices ranging in complexity from small hand-held machines used to carry out numerous tasks related to fields in the production of agricultural produce. Farm machinery is frequently utilized for agricultural cultivation and harvesting. People utilized tools to produce and harvest food in the past. These farm tools are used to maintain soil loose so that mature crops may be harvested. These devices aid in the development of tiny hand tools such as hoes, rakes, trowels, and so on, which are commonly used in gardening. Then there is an outsized implementation that resulted in the enhancement of massive hand tools such as grass shears, gardening toolsets, and so on, and these implements are produced with the goal of growing crops in mind. A rotavator or rotary tiller assembly consists of subsequent parts which are shown in fig.1.

1. Independent top mast
2. Single or multi-speed gearbox
3. Chain/gear drive
4. Blades
5. Adjustable depths kids
6. Central with offset positions

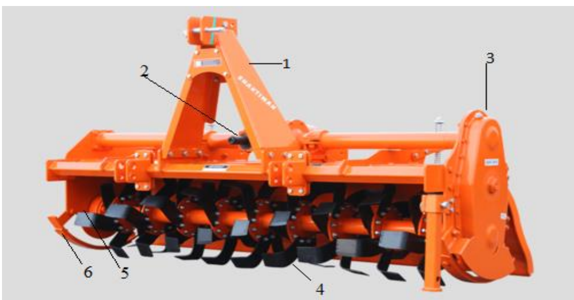


Fig-1. Components of a Rotavator

A rotavator is a type of agricultural tillage device that is often regarded as the most essential secondary production and land productivity tool. It is one of the types of equipment used by farmers to improve seedbed preparation. Furthermore, this rotavator has seven times the mixing capacity of a plough [1, 2]. The rotavator is powered by a tractor-driven Power Take-off (P.T.O) shaft with a tractor power of 30 hp, and the shape and material of the blade are L-shaped blades of High Carbon steel [3]. The design of a rotary tiller with an L-shaped blade is optimized by decreasing weight, cost, and enhancing field performance to achieve high weed removal effectiveness [4]. In general, rotavators operate well in all acceptable soil conditions but require a lot of energy, but rotary tilling saves more labor than conventional tillage methods [5].

Rotavators are increasingly being employed in agricultural applications because of their simple design and high efficiency. Using this rotavator, primary and secondary tillage operations may be combined in a single stage [6]. Despite their high energy consumption, rotary tillers have the ability to provide a wide range of tillage applications in a single step, thus the overall power required for these machines is minimal [7].

2. LITERATURE REVIEW

Kajale et al. [1] studied the optimization of rotary tillage tool component design and CAE analysis. They conducted a structural analysis of a rotavator utilizing CAD software and the finite element technique and simulation method. CAD software is used to model the numerous tillage tool parts of a tiller. This software was given all of the inputs for a 35 hp and 45 hp tractor, as well as the boundary conditions. This research identifies a suitable tolerance for changing the proportions of rotavator frame sections and side gearboxes to minimize excessive weight in a solid section while raising the blade weight for reliable strength. After demonstrating its practical results from field performance, the current model with a tillage blade is subjected to new design constraints with a shape adjustment for optimal weed removal effectiveness.

Vegad et al. [2] investigated three types of rotavator blades using Solidworks and ANSYS software (i.e. C, Hatchet, and L-shaped blade). Solidworks is being used to optimize the design of three different types of blades. High carbon steel is employed as the blade material. The optimized design of a blade indicates that stress, deformation, and mass was decreased when compared to the initial design, and that the hatchet-shaped blade is more likely to break under operational conditions than the C-shaped blade.

Tewari et al. [3] explained the design of a tractor PTO operated rotavator. The design of a rotavator for a 30 hp tractor is calculated by using design procedures. In this present work, the force acting on each blade is calculated by using a specific work method. The force exerted on each blade is determined to be 1064.1 N, and the blade thickness and cutting width are determined to be 5 mm and 30 mm, respectively.

Ravindra et al. [4] investigated how to improve the current design of the L-shaped rotavator blade. The two blade materials discussed in this study are EN 8 steel and EN 24 steel. In order to increase the strength and weed removal efficiency, the blade shape was changed and structural analysis was undertaken on both the present blade and the modified blade. High chromium steel, H13 steel, and D3 steel are all options for blade material. The modifications made to the current design yielded the greatest results with the least amount of stress and distortion.

Singha et al. [8] used the design of experiments to investigate the influence of hard-faced Cr-alloy on abrasive wear of low carbon rotavator blades. They investigated using hard facing as a surface modification approach and a Cr-based electrode in this research. A rotavator blade made of high tensile low carbon (0.3) steel is employed for their job. An experiment is used to investigate the influence of chromium alloy on the base material. The surface hardness of blades is raised once chromium is added. The wear resistance of blades is determined using the ASTM G-99 standard wear testing method. The hard-faced blades have a stronger wear resistance than conventional rotavator blades, according to the results of this study.

Mishra et al. [9] investigated the several causes of rotavator failure. The existing rotavator is analyzed by doing modeling and carrying out ANSYS analysis. EN19 was utilized for the rotavator shaft, SAE 1020 for the flange, and AISI 5140 for the bolts. They discovered that the flange material is insufficient to sustain the various sorts of forces that are applied to it. As a result, they proposed EN 19 as new material (oil Quenched & drawn).

Selvi et al. [10] conducted an experiment to develop a new geometrical model for better soil tillage. The blade is made up of three separate materials: stainless steel, mild steel, and structural steel, which are all developed using computer software. Using these three materials, static analysis was performed, and a new material that is better than that material was created, followed by the next step in the process. The major goal of this new design is to save time and money by reducing labor expenses and reducing the amount of material used. Here, a new material with excellent mechanical strength is chosen.

From the study of all the above papers, it is observed that most of the blades of the rotavator bends and breaks while cultivation. This is because the existing designs are not able to withstand the fluctuating load conditions in the fields. Due to that, the life of the blades will reduce, and hence it may not be convenient for the farmers to use them. So it is required to design a blade that withstands higher fluctuating load conditions with longer life.

3. METHODOLOGY

The designing process of a rotavator is done in one of the CAD Software that is Solidworks. After the design of a rotavator, the required model is imported into the ANSYS software for the analysis part. Static structural analysis and fatigue analysis are the types of analysis used in this work. In order to do a fatigue analysis, the foremost work is to complete the structural analysis, because the stress values are needed for the operation of fatigue analysis. The L-shaped rotavator blade is subjected to a tangential force. The static structural analysis is done to check the reaction of loads like Von-Mises stress and Total deformation. The design of the rotavator is considered safe only when the maximum stresses induced in the blade material should not exceed the yield strength of the actual material.

In order to get accurate results, the assembly design of the rotavator blade and rotavator shaft is been done.

Fig-2. Design of a Rotavator

4. DESIGN CALCULATIONS OF A ROTAVATOR

In this present study, we have designed a rotavator for a 30hp tractor. The design of a rotary tiller blade depends on the type of blade, no. of blades, and the arrangement of the blade. In order to design the rotavator, specific work becomes the basis for the design [3]. It defines how much volume of the soil, the blades will be handling. After that only we can think of the power source.

Power available at the P.T.O. Shaft:

Brake horse Power of tractor = 30 hp

So the power available at P.T.O. shaft = 0.87×30

= 26.1 hp

Assume 20% loss of power through transmission, power available at the rotavator shaft is

Power, P = 26.1×0.80

= 20.88 hp

= 15.57648 kw

Therefore, power available at the P.T.O. shaft, P = 15.6 kw

RPM of Rotor:

Let us consider forward speed of tractor, v = 3 km/h

= 0.834 m/s

Let us take velocity ratio, λ = $\frac{u}{v} = 5$ (it can vary between 2.5 to 5)

Where, u = Rotor speed, m/s

v = forward or tractor speed, m/s

$$\frac{u}{v} = 5$$

$$\frac{u}{0.834} = 5$$

Therefore, rotor speed, $u = 4.17$ m/s

Rotor speed, $u = \frac{2\pi NR}{60}$

Where, R = radius of rotor = 25 cm

$$4.17 = \frac{2\pi N \times 0.25}{60}$$

$$N = 159.28$$

Therefore, RPM of rotor, N = 160 RPM

Peripheral force acting on a constant arm:

$$\text{Power} = \text{force} \times \text{velocity}$$

$$P = k_0 \times \frac{2\pi NR}{60}$$

Where, k_0 = peripheral force, N

$$15.6\times10^3 = k_0 \times \frac{2\pi\times160\times0.25}{60}$$

$$k_0 = 3724.225668 \text{ N}$$

Specific work of a rotavator:

$$A = A_0 + A_B$$

Where, A_0 = Static specific work = $0.1C_0 k_0$, kg m/cu. Decim

A_B = Dynamic specific work = $0.001\ \alpha_u u^2$ or $0.001\ \alpha_v v^2$, kg m/ cu. Decim

C_0 = Coefficient relative to the soil type = 2.5 to 5, take $C_0 = 3$

K_0 = Specific strength of soil, kg/cu. Decim

α_v & α_u = Dynamical coefficients, kg s^2/m^4

$$A_0 = C_0 \times k_i$$

$$= 3 \times 0.15$$

$$= 0.45 \text{ kg/cm}^2$$

$$A_B = \alpha \times u^2$$

$$= 500 \times (4.17)^2$$

$$= 8694.45 \text{ kg/m}^2$$

$$= 0.869445 \text{ kg/cm}^2$$

Specific Work, $A = A_0 + A_B$

$$= 0.45 + 0.869445$$

$$= 1.319445 \text{ kg/cm}^2$$

Moment acting:

$$M = \frac{A \times Z \times L \times a \times b_m}{2\pi}$$

Where, a = depth of operation = 10 cm

A = Specific Work, kg/cm^2

Z = No. of blades in one plane

L = Bite length = $\frac{2\pi R}{\lambda Z}$

b_m = Width of the machine, cm

$$M = \frac{A \times Z \times \frac{2\pi R}{\lambda Z} \times a \times b_m}{2\pi}$$

$$= \frac{A \times R \times a \times b_m}{\lambda}$$

$$= \frac{1.319445 \times 25 \times 10 \times b_m}{5}$$

$$M = 65.97225\ b_m$$

$$\text{Where, } M = k_0 \times R$$

$$M = 3724.225668 \times 25$$

$$= 93105.6417 \text{ N cm}$$

$$= 9490.891101 \text{ kg cm}$$

$$65.9225 b_m = 9490.891101$$

$$b_m = 143.970$$

$$= 144 \text{ cm}$$

Number of flanges on rotavator shaft:

$$n_f = \frac{\text{Width of machine} (b_m)}{\text{distance between two flanges}}$$

$$n_f = \frac{144}{20}$$

$$= 7.2$$

Therefore the number of flanges, n_f = 8

Number of Blades:

$$n_b = (2 \times 2) + (6 \times 4)$$

$$= 28$$

Note: Each flange consists of 4 blades but the outermost rotor on both ends consists of 2 blades on each.

Arrangement of the blades on the flanges at an angular interval:

$$A^0 = \frac{360}{i\,Z}$$

$$= 12.857142^0$$

Force acting on one blade:

$$k_0 = 3724.225668 \text{ N}$$

$$= 379.635644 \text{ kg}$$

Assuming one-fourth of the blade will strike on the soil surface,

$$\text{Force, } k_0 = \frac{379.635644}{28/4}$$

$$= 54.23366343 \text{ kg}$$

Considering the factor of safety as 2, the force acting on one blade is given as

$$k_0 = 54.23366343 \times 2$$

$$= 108.467 \text{ kg f}$$

$$= 1064.06 \text{ N}$$

Moment acting on blade:

$$M = k_0 \times R$$

$$= 1064.06 \times 0.25$$

$$= 266.016 \text{ Nm}$$

Bending stress:

$$\boldsymbol{\sigma} = \frac{M \times Y}{I}$$

Where, M = Moment acting on blade = $k_0 \times R$

I = Moment of inertia = $bh^3/12$

Y = h/2

h = width of the blade

b = thickness of the blade

$$\boldsymbol{\sigma} = \frac{M \times \left(h/_2\right)}{bh^3/_{12}}$$

$$= \frac{M \times \left(h/_2\right)}{\frac{h}{6} \times h^3/_{12}}$$

$$= \frac{36M}{h^3}$$

$$= \frac{36 \times 266.016}{h^3}$$

$$\text{Therefore, } \boldsymbol{\sigma} = \frac{9576.580291}{h^3}$$

Torsional Stress:

$$\sigma_t = \frac{2 \times k_0 \times S}{\frac{2}{9} \times b^2 \times h}$$

$$= \frac{2 * 108.4673269 \times 0.6}{\frac{2}{9} \times \left(\frac{h}{6}\right)^2 \times h}$$

$$= \frac{21086.04835}{h^3}$$

Maximum Shear Stress:

$$\tau = \frac{1}{2}\sqrt{\sigma^2 + 4\sigma_t{}^2}$$

$$\tau = \frac{1}{2}\sqrt{\left(\frac{9576.580291}{h^3}\right)^2 + 4\left(\frac{21086.04835}{h^3}\right)^2}$$

Here shear stress of high carbon steel has been taken as 1080 kg/cm^2

$$1080 = \frac{1}{2}\sqrt{\frac{1870196630}{h^6}}$$

$$h^3 = \frac{43245.77008}{2160}$$

$$h^3 = 20.02118985$$

$$h = 2.7153 \text{ cm}$$

$$h = 3 \text{ cm}$$

Therefore, $b = h/6$

$$b = 3/6$$

$$b = 0.5 \text{ cm}$$

Rotavator shaft design:

$$\tau = \frac{16M}{\pi d^3}$$

Considering yield Stress of high carbon steel as 525 MPa

$$\tau = \frac{\sigma_{yt}}{2}$$

$$= \frac{525}{2}$$

$$= 262.5 \text{ N/mm}^2$$

$$262.5 = \frac{16 \times 266.0161192 \times 10^3}{\pi d^3}$$

$$d^3 = \frac{1354808.97}{262.5}$$

$$d^3 = 7741.765543$$

$$d = 17.2815$$

Therefore, the diameter of the rotavator shaft, d = 20 mm.

Table-1. Specifications of an existing designed rotavator

S.No	Notations	Parameters	Units	Dimensions
1	Working depth of a rotavator	a	mm	100
2	Working width of a rotavator	b	mm	1440
3	Rotor rpm	N	RPM	160
4	Forward speed of tractor	v	m/s	0.834
5	Rotor speed of tractor	u	m/s	4.17
6	Power of tractor	P	Hp	30
7	Vertical length of blade	L_v	mm	170
8	Horizontal length of blade	L_h	mm	130
9	Blade cutting width	h	mm	30
10	Thickness of blade	b	mm	5
11	Radius of curvature	R	mm	28
12	Blade angle	**θ**	degree	90
13	Chamfer of blade	CH	mm	$5*45^0$
14	Total no. of blades	n_b	-	28
15	Total number of flanges	n_f	-	8
16	No. of blades on each flange	z	-	4
17	Force acting on constant arm	k_0	N	3724.225
18	Specific work done by a rotavator	A	Kg/cm^2	1.319445
19	Diameter of rotavator shaft	d	mm	20
20	Force acting on each blade	k_0	N	1064.1

Materials

Materials used in the production of rotavator blades should have mechanical features such as high wear resistance, compressive strength, density, and be cheaply accessible. The other four materials, in addition to High Carbon steel, have been chosen for this experiment.

Table-2. Material Properties of rotavator blade

Material Name	Yield Stress (MPa)	Poisson Ratio	Density (kg/m^3)	Elastic Modulus (N/mm^2)
High Carbon Steel	525	0.29	7480	1.97e5
EN24 Steel	850	0.3	7840	2.10e5
EN8 Steel	850	0.3	7850	2.05e5
Boron Steel	1350	0.3	7880	2.03e5
Chromium Steel	700	0.29	7700	2.05e5

5. ANALYSIS

One of the most commonly used software for analysis purposes is ANSYS software because the results obtained by ANSYS are close to accurate values. We can perform a different kind of engineering problems in ANSYS software. The different types of analysis we can perform are Static-Structural Analysis, Steady State Thermal Analysis, Transient Structural, Transient Thermal, Modal, Harmonic, Buckling, Fatigue, Computational Fluid Dynamics, etc. the modeling of the rotavator is done using CAD software that is Solidworks. A rotavator is designed by taking the dimensions obtained in design calculations.

A Static Structural Analysis and fatigue analysis are done with calculated loading conditions. The material properties are to be changed in the material library section in ANSYS. We can create a new material if it is not available in the library or can edit the existing material's properties. Then the model is imported into ANSYS workbench as .stp format using geometry tab in ANSYS standalone system. We will generate a mesh after loading the model into the programe and specifying the mesh size. The model will next be subjected to boundary conditions.

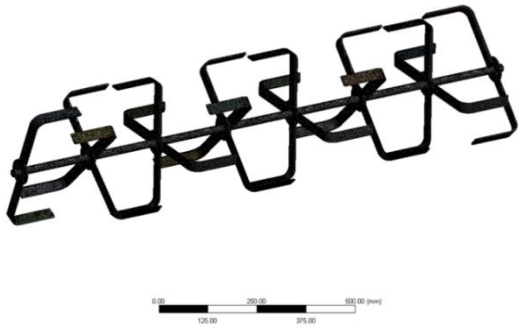


Fig-3. Mesh of a rotavator

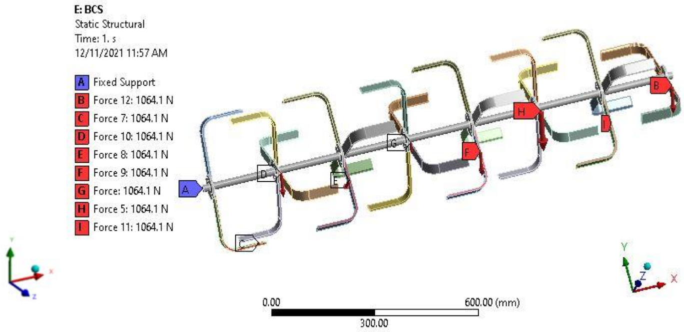
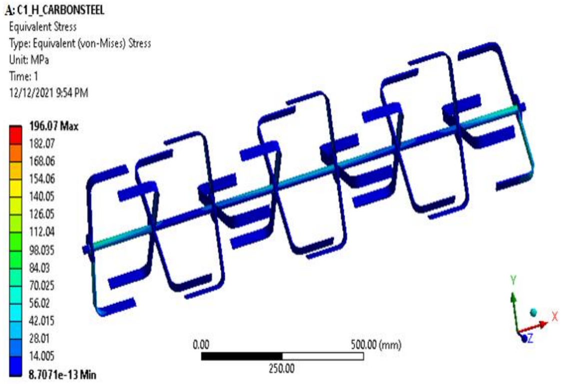


Fig-4. Boundary conditions of a rotavator

After meshing the boundary conditions have to be given. Those conditions are forces acting on each blade as 1064.1 N for the respective design and model as the values obtained from the calculation.

6. RESULTS & DISCUSSION

With these inputs, we can generate the solution for equivalent (von-mises) stress, deformation, and fatigue life. In the solution tab, we insert the Equivalent (Von-Mises) stress, total deformation, fatigue life and we click on Solve. The below figures are the results of equivalent (von-mises) stress, deformation, and fatigue life of a rotavator blade made of High Carbon Steel.



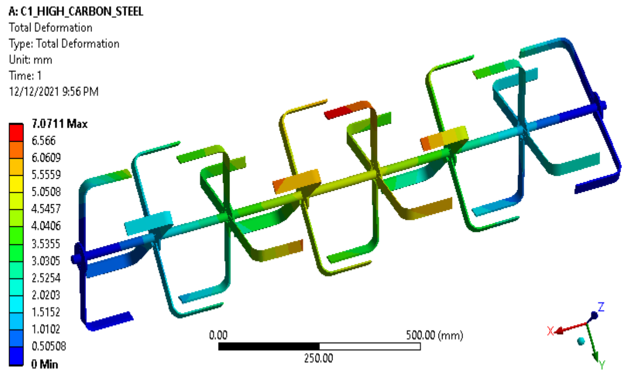


Fig-5. Equivalent (von-mises) stress **Fig-6.** Total deformation

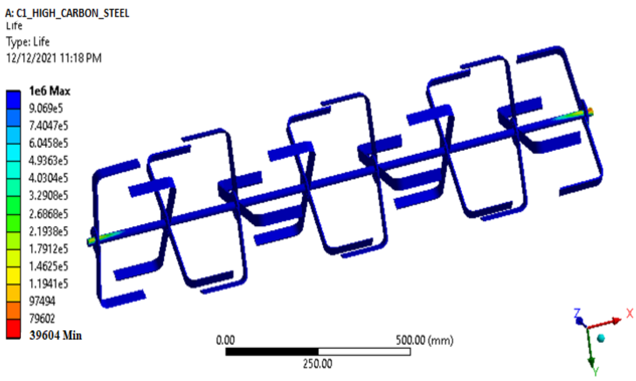


Fig-7. Fatigue Life

The below figures are the results of equivalent (von-mises) stress, deformation, and fatigue life of a rotavator blade made of Boron Steel. The equivalent (von-mises) stress, total deformation, and fatigue life results of rotavator blade made of other different materials such as EN24 steel, EN8 Steel, and Chromium Steel are found to be 181.74, 170.38, 169.65 MPa, 6.798, 6.3839, 6.4494 mm and 49525, 50373, 51155 cycles.

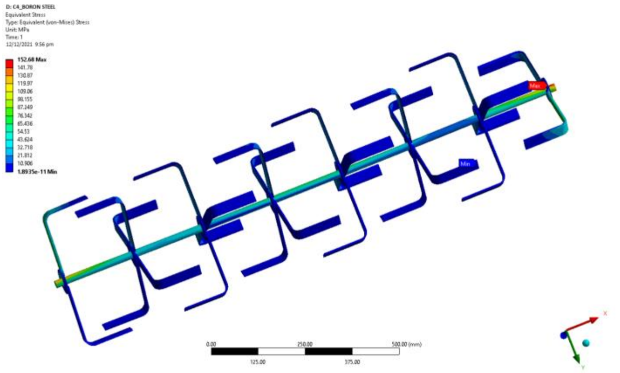


Fig-8 Equivalent (von-mises) stress

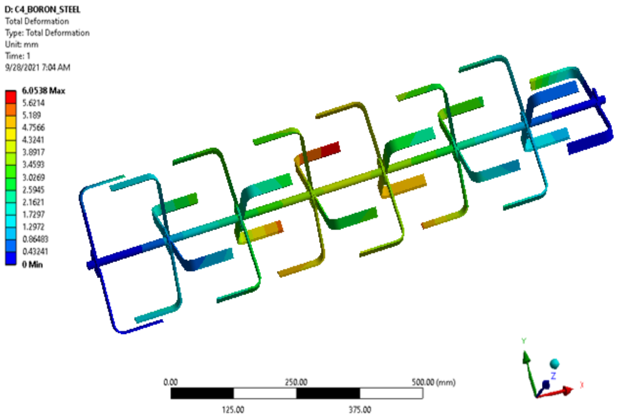


Fig-9 Total Deformation

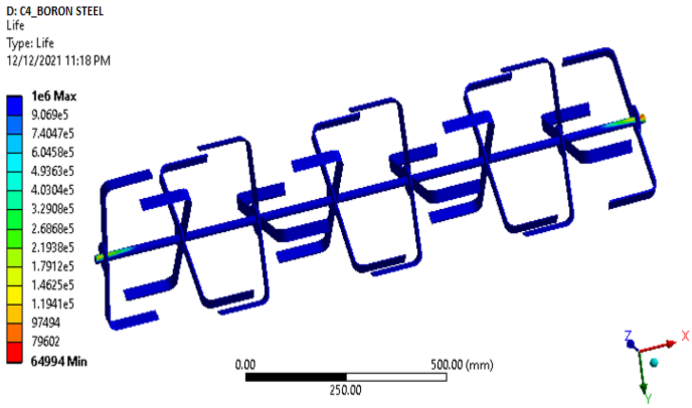


Fig-10 Fatigue Life

From the results, the best material from the existing design is found as boron steel with Equivalent (von-mises) stress as 152.68 MPa, Total deformation as 6.0538 mm, and fatigue life as 64994 cycles.

Table-3. Results of existing design of a rotavator

Material Name	Equivalent (von-mises) Stress (MPa)	Deformation (mm)	Fatigue Life (cycles)
High Carbon Steel	196.07	7.0711	39604
EN24 Steel	181.74	6.798	49525
EN8 Steel	170.38	6.3839	50373
Boron Steel	152.68	6.0538	64994
Chromium Steel	169.65	6.4494	51155

It is also studied that the effect of radius of curvature on blade strength. The rotavator blade is modeled and analyzed by considering different radius of curvatures such as R24, R34, R38, and R40. Using ANSYS software the model has analyzed the results like equivalent (von-mises) stress, deformation, and fatigue life for the different radius of curvatures that are shown below.

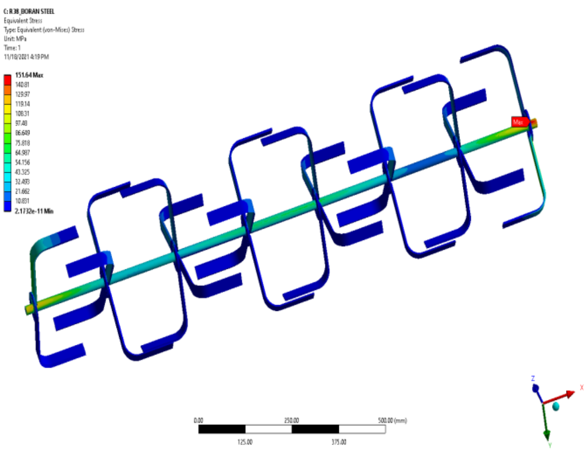


Fig-11 Equivalent (von-mises) stress

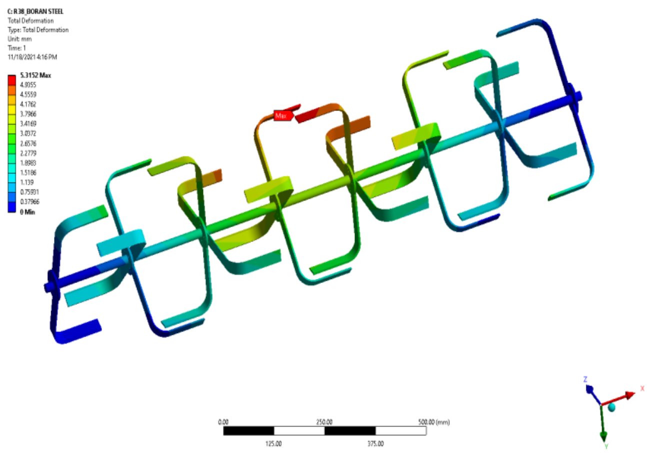


Fig-12 Total Deformation

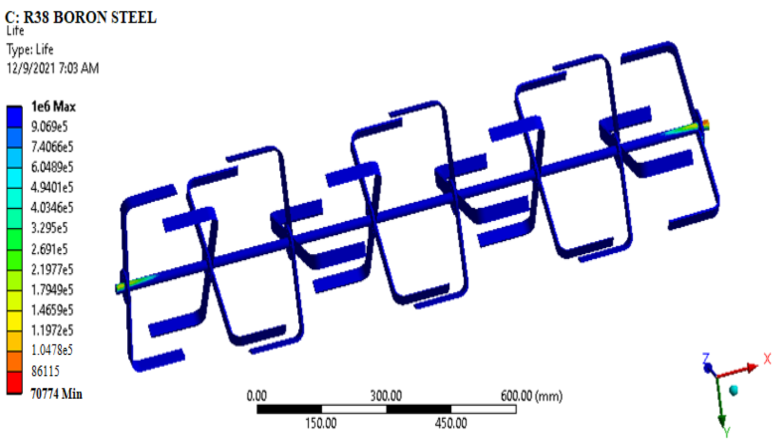


Fig-13 Fatigue Life

The boron steel blades of varying radii are modeled and analyzed to get the optimum results. From the results, it is observed that the values of equivalent (von-mises) stress, deformation, and fatigue life of R24, R34, R38, and R40 radius of curvatures are found to be stress values as 155.06 MPa, 151.79 MPa, 151.64 MPa, and 151.55 MPa, deformation values as 6.9682mm, 6.2908 mm, 5.3152 mm, and 6.9733 mm, fatigue life values as 65212, 70513, 70774, and 70914 cycles. Comparing the results of the R28 radius of curvature with the other four different radii of curvatures is as shown below.

Table-4. Results of modified design of a rotavator

Radius of Curvature	**Equivalent (von-mises) Stress (MPa)**	**Deformation (mm)**	**Fatigue Life (cycles)**
R24	155.06	6.9682	65212
R28	152.68	6.0538	64994
R34	151.79	6.2906	70513
R38	151.64	5.3152	70774
R40	151.55	6.9733	70914

By comparing all the obtained results, the best design of a rotavator blade is found as R38 with minimum deformation of 5.3152 mm and considerably has a longer fatigue life of 70774 cycles.

7. CONCLUSION

This research focuses on the design and analysis of a rotavator by considering the blade as an L-shaped rotavator blade. From the research, we observed that the rotavator blade is usually manufactured from High Carbon Steel and mild steel, whereas in our study in addition to High Carbon Steel the four different materials such as EN24 Steel, EN8 Steel, Boron Steel, and Chromium Steel are used. These materials have different properties and they are simulated in ANSYS for static structural analysis and fatigue analysis. Thus the static structural analysis and fatigue analysis gives a detailed study about those five materials such as equivalent (von-mises) Stress, deformation, and fatigue life. Out of different blade materials, it is observed that boron steel is best in view of lower deformation with 6.0538 mm and higher fatigue life of 64994 cycles. So boron steel is selected as the best material for the further process. To see the effect of curvature radius, different radii are taken for boron steel blades such as R24, R34, R38, and R40. By considering the above radius of curvatures the rotavator is modeled and analyzed for the results like stress, deformation, and fatigue life. From the results, it is observed that R38 is the best radius of curvature in view of lower deformation 5.3152 mm and also has a higher fatigue life of 70774 cycles. It is concluded that the best blade design for a rotavator blade is boron steel with an R38 radius of curvature in view of a lower deformation and considerably has longer fatigue life.

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