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Design and development of rotavator cutting tools using advanced mechanization technology for farm fields: A research review

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Abstract

The escalating cost of agricultural land preparation due to rising fossil fuel prices necessitates the adoption of efficient and cost-effective tillage methods. Rotary tillers (rotavators) are recognized as suitable machinery for seedbed preparation, with their blades being critical components directly interacting with the soil. These blades face significant challenges due to impact and friction, leading to wear and reduced service life. This research review synthesizes existing studies on the design and development of rotavator blades, emphasizing the application of advanced mechanization technologies such as Computer-Aided Design (CAD) and Finite Element Analysis (FEA). The review explores various approaches to enhance blade lifespan and performance, including material selection (High Carbon Steel, EN Steels, Boron Steel, Chromium Steels), geometric optimization (radius of curvatures), and analysis techniques (static structural and fatigue analysis). Furthermore, it considers the practical implications of blade design on weed removal efficiency and overall land preparation effectiveness. This review aims to provide a comprehensive understanding of the current advancements and future directions in designing robust and efficient rotavator cutting tools for improved farm field preparation.

Keywords: Rotavator, cutting tools, agricultural mechanization, CAD, FEA, blade design, material selection, fatigue analysis, weed removal, land preparation.

Introduction

Farm machinery and implements are integral to modern agricultural production, encompassing a wide range of tools that enhance efficiency across various farming operations [Farm machinery and/or implements]. Historically, manual tools were employed for tasks like loosening soil and harvesting crops [Vegad, & Yadav (2018)] [36] [Farm machinery and/or implements]. The evolution of agricultural technology led to the development of larger implements aimed at increasing productivity [Farm machinery and/or implements]. Among these, the rotavator, or rotary tiller, has emerged as a crucial secondary tillage implement, highly regarded for its effectiveness in seedbed preparation [A rotavator is a type of agricultural tillage device]. It offers a significant advantage by providing up to seven times the mixing capacity of a traditional plough. Powered by a tractor's Power Take-off (P.T.O.) shaft, typically with a 30 hp tractor, the rotavator utilizes a series of blades, often L-shaped and made of High Carbon steel, to cut and pulverize the soil in a single pass [A rotavator is a type of agricultural tillage device, [Kepner, *et al* (1977), Tewari *et al*. 2018] [19, 34]. This capability allows for the conjugation of primary and secondary tillage operations into a single stage, potentially reducing the total power needed despite its inherent high energy consumption [Culpin, 1981] [8]. Furthermore, the direct power transmission to the tillage blades in rotavators results in high power transmission efficiency, and the phenomenon of negative traction can decrease the required tractive force, enabling the use of smaller tractors [Culpin, 1981, Bernacki *et al* (1972)] [8, 5].

Rotary tilling is a prevalent tillage operation in Indian farming due to its superior ability to mix, flatten, and pulverize soil [Rotary tilling is a widely used tillage operation (Araya, K., & Gao, R. (1995) [2]. While its use has been traditionally limited to shallow tillage due to high energy demands, recent interest has grown in deep rotary tillage with reduced energy consumption to address soil fatigue and facilitate the conversion of paddy fields [Rotary tilling is a widely used tillage operation]. The rotavator's effectiveness in intensive tillage is well-established, consistently producing optimal results across various soil types, conditions, and residue amounts, with adjustable working depths and soil finishes [Rotary Tiller or rotavator is a highly effective machine].

However, the continuous and fluctuating impact of soil on the rotavator blades leads to high stress, particularly at the blade tips and critical edges [The continuous fluctuating impact of soil]. This results in blade wear after a certain period, influenced by soil type, with local blades lasting approximately 20-200 hours and imported blades 300-350 hours under normal soil conditions [Saxena and Singh, 2010] [27]. While material characterization has been explored to enhance blade service life, these efforts have not consistently addressed the overall cost of the blades [Considering this, some work on material characterization]. Another critical avenue for improvement lies in the geometry of the tiller blades, considered a primary factor influencing cutting efficiency [Singha, S., & Garga, J. (2018), Jain-Song, 2007] [32, 14]. Consequently, there is a significant need to enhance blade design through geometrical modifications to reduce both blade cost and land preparation expenses (Bhargavi, A., & Varma, B. M. (2021) [7] [Hence there is a need to improve the design]. This paper aims to describe the design improvement and development of rotavator blades using computational methods(Yong & Hanna (1977), Selvi, K. C. (2017)) [37, 28], specifically Computer-Aided Design (CAD) and potentially Computer-Aided Manufacturing (CAM) and Finite Element Analysis (FEA) [This paper describes the design improvement and development of blade through computational methods (Hughes, T. J. R. (2000) [13], Jain-Song, J. (2007) [14], Subrata Kr. Mandal *et al* 2013) [21], This approach involves analyzing existing designs, exploring new geometries, considering material properties, and evaluating performance through simulation to ultimately develop more durable, efficient, and cost-effective rotavator cutting tools for farm field preparation.

Technology Used to Develop Prototype Using Methods and Materials

The Finite Element Method (FEM) is one of the primary techniques employed in the evaluation of structural behavior under both static and dynamic loading conditions (Shende *et al* 2011) [29]. It allows for performance analysis and design improvements before physical prototyping. According to Reddy (1984) [25], the FEM process includes:

A. Discretizing the domain into finite elements,
B. Deriving element equations,
C. Assembling the equations to form a complete system,
D. Applying boundary conditions,
E. Solving the assembled equations, and
F. Post-processing the results.

ANSYS, a general-purpose FEM-based software, is used extensively for simulating real-world physical behavior in a fully three-dimensional environment without compromising on geometric details. Researchers have utilized FEM to design tillage tools and analyze the interaction between soil and implements, often using simple geometries like blades to simplify analysis (Godwin and Spoor, 1977, Matin *et al* (2015)) [11, 23].

Computer-Aided Engineering (CAE) Tools

CAE tools support engineering analysis and the evaluation of product designs. These tools include Finite Element Analysis (FEA), tolerance analysis, design optimization, mechanism analysis, and mass property analysis, enabling engineers to simulate and verify performance before physical prototyping.

Blade Details and Material Selection

Based on market research and literature review, three major blade types are identified in rotary tillers—L-shaped, C-shaped, and J-shaped blades (Subrata Kr. Mandal *et al*., 2013) [21]. Among these, L-shaped blades are preferred in trashy field conditions due to their superior weed-killing efficiency and minimal soil pulverization (Adams (1959), Mandal, S. K., & Bhattacharyya, B. (2016)) [1, 22]. In India, L-shaped blades are most commonly used, typically mounted as three left-handed and three right-handed blades per flange (Kankal, *et al* (2020), Jakasania, R. G. (2016), Bilalis, N. (2000)) [17, 15, 6].

Methodology for Prototype Development

The prototype design begins with 3D modelling in SolidWorks, a widely used CAD software. The designed model is then imported into ANSYS for further simulation. The analysis includes:

- Static Structural Analysis to evaluate stress distribution (Von-Mises stress) and total deformation.
- Fatigue Analysis, which depends on results from structural analysis to assess component durability under repetitive loads (Fig.1 and fig.2).

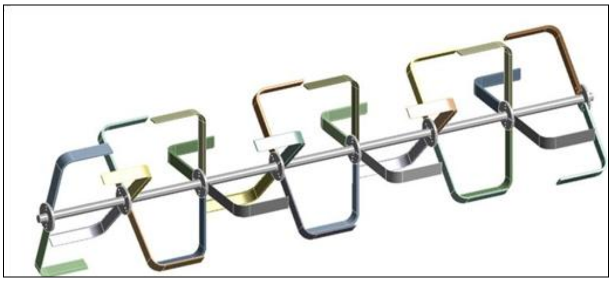

Fig 1: Design of a Rotavator (Bhargavi, A., & Varma, B. M. (2021) [7]

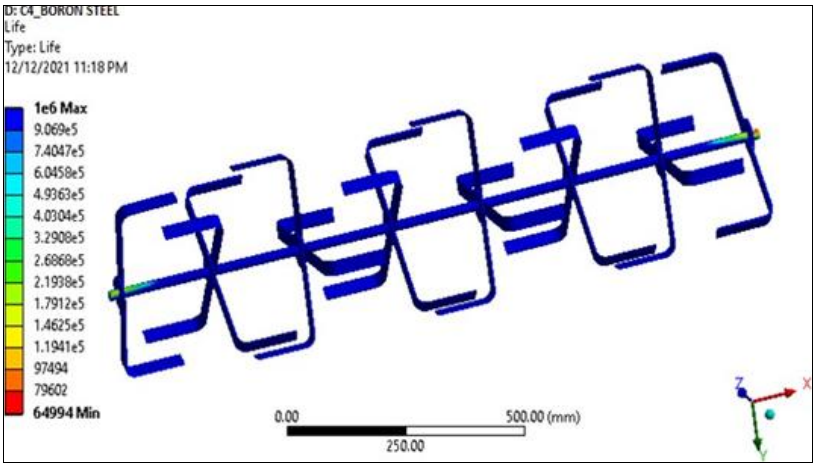

Fig 2: Fatigue Life **(**Bhargavi, A., & Varma, B. M. (2021) [7]

Table 1: Results of existing design of a rotavator (Bhargavi, A., & Varma, B. M. (2021) [7]

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

The primary objective is to ensure that the stresses induced in the blade do not exceed the yield strength of the chosen materials, thus confirming the design's safety and durability (Table.1).

While High Carbon Steel and Mild Steel are commonly used materials for manufacturing blades, this study explores additional options such as EN24 Steel, EN8 Steel, Boron Steel, and Chromium Steel, all simulated under identical loading conditions using ANSYS for comparative evaluation (Srivastava, *et al* (2006). Kankal, *et al* (2016), Mahal *et al* (2012)] [33, 18, 20].

Rotavator Overview

A rotavator is a rotary tillage machine used for soil pulverization, mixing fertilizers, seedbed preparation, and weed control. It is a critical secondary tillage implement offering efficient power transfer from the tractor's PTO (Power Take-Off) directly to the soil. Compared to traditional tillage tools, rotavators can reduce time by 30-35% and operational costs by 20-25%.

Key components of a rotavator include:

1. **Independent Top Mast:** Transfers power from the PTO to the rotavator.
2. **Gearbox:** Reduces standard PTO speed from 540 rpm to 204 rpm.
3. **Chain/Gear Cover Part Flange:** Supports the gear mechanism.
4. **Blades:** Typically L, J, or C shaped, made of materials like carbon steel (composition: C 0.52%, Mn 0.72%, Si 1.56%).
5. **Chain/Gear Cover Part:** Protects internal gear and chain systems.
6. **Frame and Cover:** Adjustable rear cover helps control soil pulverization.
7. **Adjustable Depth Skids:** Regulates blade penetration depth.
8. **Offset Adjustable Frame:** Supports the rotary shaft and blades.

Modelling and Modification

Using the CAD/CAE approach, a modified L-type rotavator blade was developed with a saw-type cutting edge for improved performance (Figure 3) [Subrata Kr. Mandal *et al* 2013, Frain, G. (1988), Godwin, R. J., & Spoor, G. (1977)] [21, 9, 11]. The aim of this modification was to increase weed removal efficiency and improve soil bed quality (Beeny, J. M., & Khoo, D. C. (1970) [3], Ben Yahia, Logue, & Khelifi, M. (1999) [4].

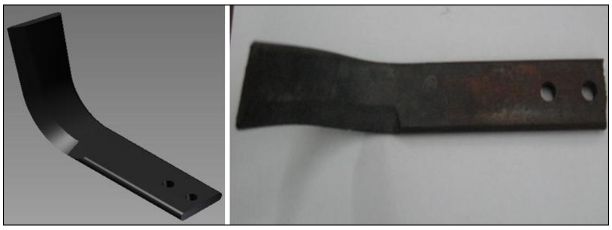

Fig 3: Geometry (3D Model) the developed Blade (Subrata Kr. Mandal *et al* 2013) [21]

Field Testing of Modified Blade

The modified blade was physically tested in field conditions and demonstrated high weed removal efficiency and excellent soil bed preparation, confirming its enhanced performance over conventional designs Fig 4 and Fig5 (Shinde, G. U., & Kajale, S. R. (2012), Shibusawa, S. (1993), Kalpande, & Pawar (2021)) [31, 30, 16].

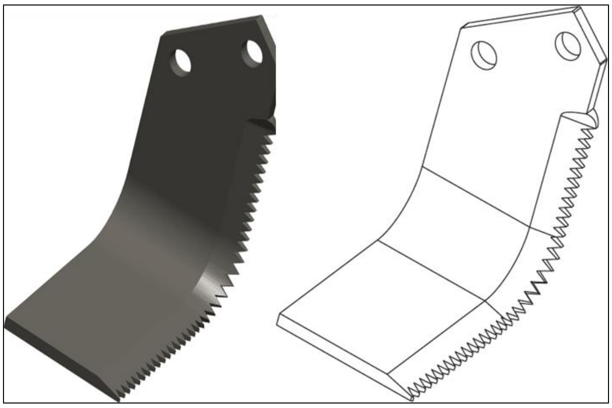

Fig 4: Modified L-Rotavator Blade with saw teeth (Kalpande, & Pawar (2021)) [16]

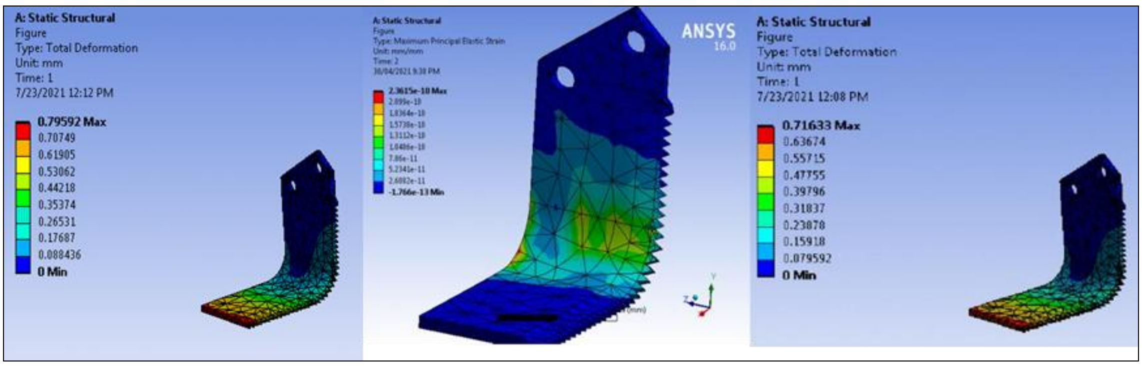

Fig 5: Results With various load with Different Material (Kalpande, & Pawar (2021)) [16]

Conclusion

The application of Computer-Aided Design (CAD) has proven to be an invaluable tool in the efficient development of critical agricultural components, as demonstrated in the design and development of the L-type rotavator blade, a key element of tractor-mounted rotavators [Subrata Kr. Mandal *et al* 2013] [21]. Finite Element Analysis (FEA) further enhances this process by enabling the investigation of stresses experienced by the designed components under operational loads [Subrata Kr. Mandal *et al* 2013, Gill *et al* 1971 & 1996,] [21, 10]. Comparative studies between the developed L-type blade and commercially available C and J-type blades have indicated that the L-type design exhibits minimal deformations and stresses, suggesting an enhanced material lifespan [Subrata Kr. Mandal *et al* 2013] [21].

Further in-depth analysis, incorporating static structural and fatigue assessments across various blade materials, reveals that Boron steel presents an optimal balance of lower deformation and higher fatigue life compared to High Carbon Steel, EN24 Steel, EN8 Steel, and Chromium Steel [Topakci, *et al* (2008)] [35,]. Geometric optimization, specifically exploring different radii of curvature for Boron steel blades, identified an R38 radius as the most favorable, yielding the lowest deformation and the longest predicted fatigue life. This suggests that a Boron steel blade with an R38 radius of curvature represents an improved design for enhanced durability and performance.

The modification of the L-type rotavator blade to incorporate saw teeth, analyzed using CAD/CAE approaches, represents a targeted effort to improve soil bed cultivation and, particularly, weed removal efficiency [Kalpande, & Pawar (2021)] [16]., Salokhe *et al* 1993 [26]. FEA results indicate that this modified L-type blade with saw teeth remains structurally safe under operational loads [Kalpande, & Pawar (2021)] [16]. Comparative analysis of Gray Cast Iron and Structural Steel as potential materials for this modified design, under varying load conditions, revealed that while Gray Cast Iron is more cost-effective, Structural Steel exhibits lower deformation and stress, indicating superior stiffness [Kalpande, & Pawar (2021)] [16]. Importantly, both materials demonstrated maximum stress levels within permissible limits across the tested load range [Kalpande, & Pawar (2021)] [16]. Furthermore, variations in blade geometry were shown to influence the deformation and stiffness of the rotavator blade [Kalpande, & Pawar (2021)] [16].

In the design and development of rotavator blades significantly benefit from the application of advanced mechanization technologies like CAD and FEA. These tools enable the optimization of blade geometry, material selection, and the evaluation of structural integrity and fatigue life. The research highlights the potential of Boron steel with an optimized radius of curvature for enhanced durability and the effectiveness of modified blade designs, such as those incorporating saw teeth, for improved soil cultivation and weed management. The findings underscore the critical role of blade design in rotavator performance and provide valuable insights for the development of more efficient and longer-lasting cutting tools for farm field preparation.

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