

Development of a Nine-Tyne Cultivator Using EN45 and Boron Steel

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Abstract: *The nine-tyne cultivator is widely used for soil loosening, weed removal and seedbed preparation. Existing machines built largely from mild steel (MS), which has a yield strength of only about 250 MPa, show low bending and breaking strength, and customers have reported tyne bending and premature failure during field operation. The failure is attributed to cantilever bending near the frame clamp, shock loads from stones and roots, stress concentration at bolt holes and sharp corners, increased draft in hard soil, and rapid abrasive wear of the share.*

This paper reviews the literature on structural analysis, wear behaviour, heat treatment and draft force of cultivator tynes. The reviewed studies show that tyne stress depends on shovel shape and soil type, that wear varies with soil, moisture and tyne position, and that boron steels offer better hardenability and wear resistance. No reviewed study compares EN45 and boron steel directly for a tillage implement, which forms the research gap. A component-wise material approach is therefore proposed for a modified nine-tyne cultivator: EN45 spring steel for the main frame and tynes (bending strength and durability), and boron steel for the soil-engaging shovel/share (abrasion resistance). On indicative property data, both steels have several times the yield strength and hardness of MS.

To obtain the full benefit of the new materials, the paper describes supporting design improvements (fillet radii, gussets, bolted tyne clamps and a replaceable bolt-on share), a heat-treatment route for each material, an ANSYS-based finite element setup comparing the MS baseline and the proposed design under identical loads (stress, deformation and factor of safety), and a laboratory and field testing plan covering composition, tensile, hardness, impact, microstructure, abrasive wear, draft and durability tests. The final design will be judged on technical performance and cost per hectare.

The work is at the progress stage: the existing design has been studied and the failure analysis completed, while CAD modelling and ANSYS analysis are being prepared. Numerical results will be added after completion of the analysis and testing.

Keywords: nine-tyne cultivator, EN45 steel, boron steel, tyne failure, wear resistance, heat treatment, finite element analysis

I. INTRODUCTION

The nine-tyne cultivator is a tillage implement used for soil loosening, weed removal and seedbed preparation. In the existing design, the major components are made of mild steel, which has low bending and breaking strength. Customers have reported tyne bending and premature failure during field operation. Tyne bending affects the working position and performance of the implement, and premature failure increases maintenance and replacement requirements.

This project develops a modified nine-tyne cultivator without changing the basic working concept. EN45 steel is considered for the main frame and tynes for higher strength, durability and service life. Boron steel is considered for the shovel/share because it works directly with soil and is exposed to abrasive wear. Design improvements and proper heat treatment are included so that the full benefit of the new materials is obtained, and CAD modelling and structural analysis will check the design before prototype implementation. The overall purpose is to improve strength, durability, wear resistance and service life.



The remainder of this paper is organised as follows. Section 2 reviews the literature. Section 3 analyses the failure of the existing MS tyne. Section 4 compares the candidate materials. Section 5 states the research gap, problem statement and objectives. Sections 6 to 9 describe the proposed design improvements, heat-treatment route, analysis setup and testing plan. Sections 10 to 12 cover risks, expected outcomes and conclusions.

II. LITERATURE REVIEW

Five studies form the core of the review, covering tyne stress analysis, boron steel wear, heat treatment, field wear and draft force. Earlier finite element studies of tynes are also relevant [1], [3], [4].

Sr. No.	Authors and Source	Findings
1	Hashaam et al. (2023), <i>Research in Agricultural Engineering</i> , 69(3), 107-117 [2]	3D FEM showed that tyne stress and deformation depend on shovel shape and soil type. Loam produced higher stress than sand. Useful for nine-tyne structural design.
2	Bialobrzaska and Kostencki (2015), <i>Wear</i> , 328-329, 149-159 [5]	Abrasive wear resistance differed among low-alloy boron steel grades. Standard abrasion testing followed by field testing is recommended. EN45 was not tested.
3	Guo, Sun, Guo and Fu (2024), <i>Agriculture</i> , 14(9), 1555 [6]	27MnCrB5 showed better hardenability than 65Mn spring steel. Heat treatment improved strength and toughness. Useful for comparing EN45 and boron steel.
4	Owsiak (1999), <i>Soil and Tillage Research</i> , 50(3-4), 333-340 [7]	Wear of spring tyne cultivator points depended on soil, moisture, travel distance and tyne position, and was 40-100% higher in sandy loam. These conditions must be controlled in testing.
5	Abbaspour-Gilandeh et al. (2020), <i>Agriculture</i> , 10(5), 145 [8]	Draft force increased with speed and depth and decreased with soil moisture. Tests should measure total and per-tyne draft under fixed conditions.

2.1 Structural analysis of tynes

Hashaam et al. [2] show that stress and deformation in a tyne are governed by shovel shape and soil type, with loam producing higher stress than sand. This supports modelling the tyne, shovel and soil loading together when designing the nine-tyne structure. Related finite element work on stress analysis of cultivator tynes [1], tyne geometry and soil penetration resistance [3], and cultivator design modification [4] provides further background for the analysis approach used in this project.

2.2 Wear of soil-engaging parts

Bialobrzaska and Kostencki [5] found that wear resistance differs among boron steel grades and recommend standard abrasion testing followed by field testing. Owsiak [7] showed that wear of cultivator points depends on soil type, moisture, travel distance and tyne position, with wear 40-100% higher in sandy loam. Together these indicate that wear comparisons are only meaningful under controlled soil conditions.

2.3 Heat treatment and steel selection

Guo et al. [6] reported that 27MnCrB5 boron steel has better hardenability than 65Mn spring steel, and that heat treatment improved both strength and toughness. This is relevant to the choice of boron steel for the share and to the heat-treatment route for EN45.

2.4 Draft force and operating parameters

Abbaspour-Gilandeh et al. [8] found that draft force increases with speed and working depth and decreases with soil moisture. Hard soil and high speed therefore make overloading of the tyne more likely, and field tests should measure total and per-tyne draft at fixed speed, depth and moisture.



III. FAILURE ANALYSIS OF THE EXISTING MS TYNE

The following causes of tyne bending and failure are identified for the existing MS design:

- Low yield strength. Mild steel has a yield strength of about 250 MPa and cannot be hardened effectively, so the tyne bends permanently once the working load crosses this limit.
- Cantilever loading. The tyne acts like a cantilever; the maximum bending moment occurs near the frame clamp, so bending and breakage are most likely in this zone.
- Shock loads. Stones, roots and hard soil layers create sudden loads much higher than the steady draft load.
- Stress concentration and fatigue. Bolt holes, sharp corners and weld toes can start cracks that grow under repeated loading.
- Draft increase. Draft rises with speed and working depth [8], so overloading is more likely in hard soil.
- Share wear. Abrasive soil wears the MS share quickly, and the changed share shape increases draft and loads the tyne further.

A root-cause check is planned on failed customer tynes, covering bend profile, hardness, fracture surface and crack origin.

IV. MATERIAL COMPARISON: MS, EN45 AND BORON STEEL

Property	Mild Steel (existing)	EN45 (proposed: main frame and tynes)	Boron Steel (proposed: shovel/share)
Typical grade	Low-carbon MS (e.g. IS 2062 E250, grade to be confirmed)	EN45 / 250A53 silicon-manganese spring steel	27MnCrB5 / 30MnB5 boron-alloyed steel
Yield strength (indicative)	About 250 MPa	About 800-1100 MPa (hardened and tempered)	About 1000-1400 MPa (quenched and tempered)
Tensile strength (indicative)	About 410-540 MPa	About 1100-1500 MPa	About 1400-1800 MPa
Hardness (indicative)	About 120-160 HB	About 38-48 HRC	About 45-55 HRC
Toughness	High, but yields and bends easily	Good when tempered correctly	Medium; depends on tempering
Wear resistance	Low	Medium	High
Welding / processing	Easy to cut and weld	Difficult to weld; needs preheat and stress relief, or bolted joints	Heat treat after forming; avoid welding in hardened zone
Role in cultivator	Baseline (frame, tyne, share)	Bending strength and springiness	Abrasion resistance at the soil-engaging share

Values are indicative ranges from standard grade data and depend on heat treatment. Final values will be confirmed from supplier test certificates and the project's own tensile and hardness tests.

On indicative data, EN45 and boron steel have several times the yield strength and hardness of MS. The two proposed steels are assigned by function: EN45 provides bending strength and spring behaviour for the frame and tynes, while boron steel provides abrasion resistance at the share.

V. RESEARCH GAP, PROBLEM STATEMENT AND OBJECTIVES

5.1 Research gaps

- The existing cultivator can experience tyne bending and premature failure during field operation.
- The main frame, tynes and shovel/share do not experience the same loading and wear, and have different functional requirements, so a component-wise material approach can be investigated instead of treating all components alike.



- Boron steel wear studies [5] did not test EN45, so direct comparison of EN45 and boron steel for a tillage implement is not available in the reviewed literature.

5.2 Problem statement

The existing MS-based nine-tyne cultivator has low bending and breaking strength, and customers have reported tyne bending and premature failure during field operation. These problems indicate a need to study the existing design, loading conditions and material requirements. The project therefore focuses on suitable material implementation for different components, using EN45 for the main frame and tynes and boron steel for the shovel/share. The intended outcome is improved structural strength, durability, wear resistance and service life, checked through CAD-based design development and structural analysis before practical evaluation.

5.3 Objectives

1. Study the existing nine-tyne cultivator and its working conditions.
2. Document customer feedback on tyne bending and premature failure.
3. Carry out failure analysis of the existing MS tyne to find root causes (low yield strength, shock loads, stress concentration).
4. Identify the material requirements of the main frame, tynes and shovel/share.
5. Implement EN45 steel for the main frame and tynes, and boron steel for the shovel/share.
6. Improve design details (fillets, gussets, replaceable share) and define the heat-treatment route.
7. Develop the proposed arrangement using CAD modelling.
8. Perform structural analysis to study stress, deformation and factor of safety.
9. Compare the proposed design with the existing MS design through laboratory tests and field trials.
10. Evaluate practical performance, durability-related behaviour and cost per hectare at later stages.

VI. PROPOSED METHODOLOGY

The work follows nine stages grouped into study, design and analysis, and validation:

1. Study of the existing nine-tyne cultivator
2. Study of construction and working conditions
3. Collection of customer feedback to identify tyne bending and premature failure
4. Loading study covering bending, deformation and wear requirements
5. Component-wise material selection (EN45 for main frame and tynes; boron steel for shovel/share)
6. CAD modelling of the proposed arrangement
7. ANSYS analysis to evaluate stress and deformation
8. Prototype development and practical testing
9. Evaluation of performance, durability and cost

VII. PROPOSED DESIGN IMPROVEMENTS

The material change is combined with design changes, keeping the basic working concept of the cultivator unchanged:

- Generous fillet radii at tyne bends and clamp edges to remove sharp corners that raise local stress.
- Bolt holes kept away from the maximum bending-moment zone, or reinforced with washers or bushes.
- Gusset plates or stiffeners at the tyne-to-frame clamp and at frame channel joints to share the load.
- Bolted tyne clamps with Grade 8.8 fasteners and correct tightening, instead of welding on hardened steel.
- A bolt-on replaceable shovel/share so that only the wear part is changed, not the whole tyne.
- A shear-bolt or spring-release arrangement, to be studied, so that impact with stones or roots does not break the tyne.



- Checks on tyne spacing and share angle to reduce draft and soil clogging, and paint or powder coating for corrosion protection.

7.1 Current design specification

The 9-rigid tyne cultivator modelled so far has the following features:

Item	Specification
Overall size	Length 2000 mm (6.7 ft), width 600 mm (2.1 ft), height 1050 mm (3.6 ft)
Frame and tynes	Channel-type frame; tyne plate thickness 25 mm
Soil cutting	Depth 7 inches and above; 9 inches between rows
Linkage	Heavy-duty type; linkage pin EN-8, Ø25 x 230 mm
Fasteners and weight	Grade 8.8 hardened, half-threaded; gross weight 197.3 kg
Materials (proposed)	EN45 frame and tynes; boron steel shovel/share

VIII. HEAT TREATMENT AND MANUFACTURING PLAN

- EN45 tynes and frame parts: normalise, harden (approx. 830-870 °C, oil quench) and temper (approx. 400-480 °C) to reach the target hardness.
- Boron steel share: austenitise (approx. 850-900 °C), quench, then temper at low temperature (approx. 180-250 °C) for high hardness with some toughness.
- Exact cycles will be finalised from the supplier datasheet, heat-treatment vendor advice and trial samples.
- Target hardness is a balance: too hard becomes brittle, too soft bends like MS. Tensile, hardness and impact trials will fix the range.
- Cutting, forming and drilling are done before hardening because hardened steel is difficult to machine.
- Fixtures, uniform heating and correct quenching limit distortion and quench cracks; straightness is checked after treatment.
- EN45 has high carbon and silicon, so welding needs preheat and stress relief; bolted joints are preferred.
- Batch inspection covers hardness, dimensions and visual crack checks, followed by surface coating.

IX. STRUCTURAL ANALYSIS AND TESTING PLAN

9.1 ANSYS analysis setup

- Model: CAD assembly of the nine-tyne frame, tynes and shovels, simplified by removing small features that do not affect stress.
- Material data: MS baseline, with EN45 and boron steel assigned component-wise (yield strength, tensile strength, modulus, density, Poisson's ratio) from supplier data.
- Mesh: refined at the tyne-to-frame clamp, bolt holes and fillets, with a mesh convergence check.
- Boundary conditions: frame fixed at the linkage pins (EN-8, Ø25 mm); loads applied at the shovel.
- Load cases: draft (horizontal) and vertical soil reaction from specific draft, depth and width per tyne, plus a shock-load case with a service factor from literature or field data.
- Fair comparison: the same loads and geometry are used for the MS baseline and the proposed EN45/boron arrangement.
- Outputs: von Mises stress, total deformation, factor of safety (yield strength divided by maximum stress) and critical locations.
- Results will be checked against field measurements of tyne deflection and draft.



9.2 Laboratory and field testing plan

Sr. No.	Test / Measurement	Standard / Method	Purpose
1	Chemical composition	Optical emission spectrometer (OES)	Confirm grade of EN45 and boron steel against the supplier certificate
2	Tensile test	IS 1608 / ASTM E8 [13]	Yield and ultimate strength of MS, EN45 and boron steel samples
3	Hardness test	Rockwell / Brinell	Check the result of heat treatment on tyne, frame and share
4	Impact test	Charpy impact test	Check toughness and resistance to shock loads
5	Microstructure	Metallography (optical microscope)	Check tempered structure and defects
6	Abrasive wear test	ASTM G65 dry sand/rubber wheel [12]	Compare wear of boron steel share with MS share
7	Field test: draft and deflection	Fixed speed, depth and soil moisture; load cell or dynamometer	Compare total and per-tyne draft and tyne bending, MS vs proposed
8	Field test: durability	Hours or hectares worked; share weight loss; crack inspection	Compare service life and maintenance with the MS design

X. CHALLENGES AND RISK MITIGATION

Challenge	Mitigation
Higher material cost	Compare cost per hectare of work (material + processing divided by service life), not only purchase price
Brittle fracture at very high hardness	Fix the tempering temperature through trials and Charpy impact testing
Distortion or quench cracks in long frame channels	Use fixtures and controlled quenching; check from the analysis whether the whole frame or only the tynes need hardening
Difficult welding of EN45	Prefer bolted joints; where welding is needed, use preheat and post-weld stress relief
Material availability (25 mm EN45 plate, boron share blanks)	Confirm stock and quotations early
Soil variation changes wear and draft	Repeat field trials under fixed soil, moisture, speed and depth
Workshop capability for hardened steel	Plan the processing sequence and finalise the heat-treatment vendor early

XI. EXPECTED OUTCOMES AND DISCUSSION

The proposed development is expected to improve structural strength and reduce tyne bending and deformation, improve tyne durability and the service life of critical components, improve the wear resistance of the shovel/share, improve overall working performance, and reduce frequent maintenance and replacement. The aim is a technically suitable and practically implementable cultivator design.

Indicative data show that EN45 and boron steel have several times the yield strength and hardness of MS (Section 4). Final conclusions will be based on structural analysis and practical testing, and actual numerical ANSYS results will be added after completion of the analysis. Cost will be compared as cost per hectare = (material + processing cost) divided by service life in hectares, for both the MS and the proposed design.



11.1 Project progress

Six activities are completed (existing design and construction studied; MS baseline reviewed; customer feedback identified; working conditions and loading requirements considered; material requirements evaluated; MS failure causes and MS/EN45/boron comparison prepared). Four are in progress (existing tyne dimensions and critical areas; EN45 implementation; boron steel implementation; modified design, CAD modelling and ANSYS preparation). The heat-treatment route, ANSYS setup and testing plan are drafted, and prototype development is planned.

11.2 Work plan

Literature review runs July to November 2026, component selection and design August to November 2026, fabrication September 2026 to January 2027, experimental analysis October 2026 to February 2027, testing and debugging November 2026 to March 2027, report preparation December 2026 to March 2027, and thesis/poster draft submission March to April 2027.

XII. CONCLUSIONS

- The project starts from a practical customer-reported problem: tyne bending and premature failure of the MS nine-tyne cultivator.
- The failure is linked to the low yield strength of MS, shock loads and stress concentration at critical locations.
- EN45 steel is proposed for the main frame and tynes (strength and durability) and boron steel for the shovel/share (wear resistance), on a component-wise basis.
- Correct heat treatment and design improvements are needed to get the full benefit of the new materials.
- CAD modelling, ANSYS analysis, laboratory tests and field trials will be used to validate the design.
- The final development will be judged on technical performance and cost per hectare.

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