Design and Fabrication of Ultrasonic Roller

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Abstract— This paper presents the design and fabrication of an ultrasonic roller intended for use in ultrasonic-assisted manufacturing processes. Ultrasonic rolling integrates highfrequency vi brations with conventional mechanical rolling to enhance surface finish, reduce forming forces, and improve mechanical properties of materials. The work involves detailed design, material selection, and precision fabrication of an ultrasonic roller suitable for integration with ultra sonic transducers. The fabricated roller aims to achieve high dimensional accuracy, balance, and surface quality, forming a foundation for future experimental and industrial applications in ultrasonic-assisted forming and finishing.

Keywords: Ultrasonic Roller, Ultrasonic-Assisted Rolling, Surface Finish, Material Process ing, Precision Fabrication

1. INTRODUCTION

In recent years, the demand for advanced manufacturing processes that deliver high precision, superior surface quality, and enhanced mechanical performance has grown significantly. Despite major developments in conventional forming techniques, challenges such as high forming forces, tool wear, and limited control over surface finish persist [1, 2]. Ultrasonic-assisted manufacturing has emerged as a promising approach to address these challenges by superimposing high-frequency vibrations on traditional forming operations, thereby improving process efficiency and product characteristics [3, 4].

An ultrasonic roller is a specialized tool designed to transmit ultrasonic vibrations to a workpiece during rolling or forming. Unlike conventional rollers, which rely solely on mechanical deformation, ultrasonic rollers integrate high-frequency (20–40 kHz) vibrations that act at the tool–workpiece interface. These vibrations reduce friction, enhance material flow, and result in improved dimensional accuracy and superior surface finish [7, 14, 15]. Moreover, ultrasonic energy assists in reducing residual stresses and increasing hardness in the processed materials, making it suitable for applications such as sheet metal forming, embossing, and surface texturing [10, 11].

The roller itself consists of a precision-machined cylindrical body fabricated from materials exhibiting high strength, wear resistance, and favorable acoustic properties [16, 9]. Its geometry and surface finish are carefully optimized to ensure efficient ultrasonic energy transmission while minimizing irregular or parasitic vibrations. The fabrication process involves CAD-based design, precise machining, and post-process inspection to achieve dimensional balance and surface uniformity.

Current research in ultrasonic-assisted rolling primarily focuses on the integration of ultrasonic transducers and process parameter optimization [12, 13]. However, the fabrication of an accurately machined and balanced roller is an essential prerequisite for such studies. This work aims to design and fabricate an ultrasonic roller that can serve as a reliable foundation for future ultrasonic-assisted forming systems. The scope includes detailed modeling, material selection, precision manufacturing, and preliminary mechanical inspection of the roller, excluding vibration testing or transducer integration at this stage.

The motivation behind this study stems from the realization that even minor imperfections in roller geometry or material properties can significantly affect process performance and experimental reliability. Thus, the development of a well-balanced, structurally sound roller prototype is vital for subsequent ultrasonic experimentation and industrial applications. The fabricated roller not only demonstrates the feasibility of high-precision ultrasonic tooling but also lays the groundwork for future investigations into the influence of ultrasonic vibrations on material deformation, friction reduction, and surface quality enhancement [8, 6].

2. LITERATURE REVIEW

Ultrasonic-assisted manufacturing has emerged as a promising technique to enhance material processing efficiency, improve surface quality, and extend tool life. The introduction of ultrasonic vibrations during conventional manufacturing operations such as rolling, burnishing, and forming leads to a reduction in forming forces, improvement in surface finish, and enhancement in mechanical properties. Researchers have extensively explored ultrasonic-assisted processes for various applications, yet limited emphasis has been placed on the design and fabrication of ultrasonic rollers, which are essential for stable and efficient operation.

Patil and Desai [9] reviewed the benefits of ultrasonic-assisted forming, emphasizing that the application of ultrasonic vibrations reduces energy consumption, enhances surface finish, and extends tool lifespan. reported that ultrasonic-assisted burnishing significantly improves surface hardness and residual stress distribution by inducing compressive stress layers on the workpiece. This enhances fatigue life and mechanical stability, particularly in aerospace and automotive components. explained that ultrasonic vibrations reduce friction between the tool and the workpiece, improving formability and dimensional accuracy through the acoustic softening effect.

Several studies have also analyzed material behavior under ultrasonic rolling. performed simulations to investigate the microstructural evolution in ultrasonic-assisted rolling, revealing that vibrations induce grain refinement, dislocation motion, and stress redistribution, leading to improved surface hardness and ductility. Similarly, demonstrated that ultrasonic surface rolling of 7075 aluminum alloy results in fine grain structures and compressive residual stresses, enhancing fatigue and wear resistance.

Thermal and mechanical optimization have also been a focus of ultrasonic roller research. Wang and Li [10] developed a water-cooled ultrasonic roller to address heat accumulation during continuous operation, improving vibration stability and roller lifespan.numerical modeling to study stress distribution and heat dissipation in ultrasonic systems, emphasizing the importance of proper coupling geometry. examined the effect of clamping force and preload, showing that proper mechanical coupling improves vibration transmission while preventing distortion and fatigue.

In terms of design and fabrication, Lee et al. [15] proposed an acoustic impedance matching technique to enhance ultrasonic transmission between the horn and roller. Johnson and Williams [16] highlighted that selecting materials with suitable acoustic impedance and wear resistance is critical to achieving consistent vibration transfer. investigated the impact of bearing design on vibration stability and demonstrated that optimized bearing configurations significantly reduce energy loss and misalignment effects.

Furthermore, the wear behavior and surface integrity of ultrasonic rollers under industrial operating conditions, showing that surface coatings and optimized material combinations reduce wear rates and maintain energy efficiency. introduced non-destructive testing methods for evaluating roller quality, ensuring consistency in ultrasonic energy delivery.

Despite these advancements, most research emphasizes experimental performance, vibration optimization, or process modeling rather than focusing on the design and fabrication of ultrasonic rollers themselves. The present study aims to bridge this gap by developing an ultrasonic roller with enhanced mechanical strength, acoustic transmission, and operational durability for integration into ultrasonic-assisted manufacturing systems.

3. METHODOLOGY

3.1 Introduction

This study focuses on the design and fabrication of an ultrasonic roller for future ultrasonicassisted manufacturing applications. The methodology emphasizes CAD modeling, material selection, precision machining, surface finishing, and inspection to ensure dimensional accuracy, mechanical stability, and surface quality [9, 10, 11].

3.2 Design Approach

The roller was designed using CAD software to ensure precision and manufacturability. Key design considerations included:

- Dimensions: Diameter and length were selected based on standard industrial requirements
- Geometry: Cylindrical shape with uniform cross-section for efficient vibration transmission
- Surface Quality: Smooth finish to ensure effective contact with the workpiece.
- Balance: Symmetry maintained to minimize vibration during rotation [15].

2D drawings with tolerances were generated for fabrication.

3.3 Material Selection

Hardened steel (EN8/EN24) was chosen due to its:

- High strength and toughness [16]
- Wear resistance [14]
- Machinability and heat-treatability [12]

This ensures durability, rigidity, and effective vibration transmission during ultrasonic operation .

3.4 Fabrication Process

The roller was manufactured through precision machining, heat treatment, and polishing:

- Turning, Grinding, Polishing: To achieve desired dimensions and surface finish [7].
- Heat Treatment: To enhance hardness and wear resistance .

3.5 Flowchart of Methodology

The methodology is summarized in the following flowchart showing the step-by-step approach from problem definition to final prototype.

3.6 Inspection and Validation

Post-fabrication, the roller was inspected for:

- Dimensional Accuracy: Verified using calipers and micrometers [10].
- Surface Finish: Measured with a surface roughness tester [11].
- Balance: Assessed through free rotation to ensure minimal vibration [12].

3.7 Final Prototype

A functional ultrasonic roller prototype was developed, conforming to design specifications and ready for integration with an ultrasonic transducer for experimental and industrial applications
[9].

4. COMPONENTS OF ULTRASONIC WELDING SYSTEM

4.1 Material Used for Horn

The material selection for an ultrasonic horn is crucial as it needs to balance mechanical strength and acoustic performance. Literature surveys indicate that titanium exhibits superior acoustic properties compared to other metals, with higher fatigue strength, hardness, and wear resistance than aluminum [9, 15].

Titanium 7-4 is about 15% stronger than titanium 6-4, allowing horns to withstand higher vibration amplitudes and operational pressures, ensuring reliable performance in demanding industrial applications. Coatings such as nitrides can enhance wear resistance and meet hygiene standards in food processing applications.

Aluminum alloys, particularly heat-treated types, offer good acoustic performance for less demanding applications. Aluminum horns are lightweight, easier to machine, and often chromeplated to improve durability and surface protection. Although aluminum is less expensive, titanium provides superior operational efficiency and long-term reliability when coated properly.

4.2 Specifications of Horn

Table 1 lists the specifications of the flat-face ultrasonic horn used in this project.

The flat-face horn used is shown in Figure 3. These horns are used to uniformly disperse ultrasonic energy across the workpiece surface.

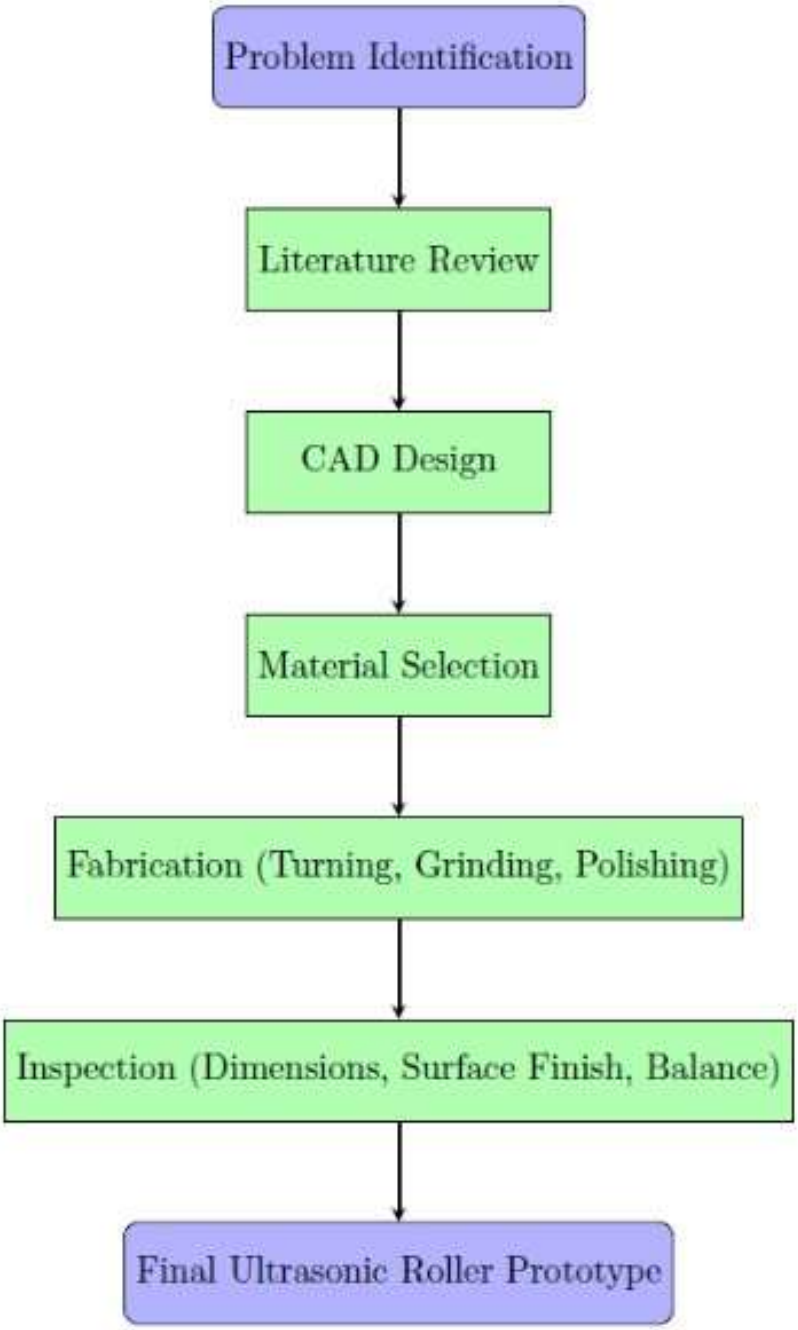

Figure 1: Flowchart of Methodology for Ultrasonic Roller Design and Fabrication

4.3 Booster

A booster is a mechanical amplifier used to increase the amplitude of vibrations from the ultrasonic transducer to the horn. The booster gain is determined by the mass ratio above and below the nodal point, with standard gain factors of 1.0, 1.5, 2.0, 2.5, and 3.0 [10].

Boosters connect the transducer and horn via threaded attachments and are made from steel, aluminum, or titanium depending on the application, vibration frequency, horn size, and

Figure 2: Flat-face Ultrasonic Horn

Table 1: Specifications of Ultrasonic Horn material type. Selection criteria include:

Specifications	Details
Material	Steel
Size	110 mm
Usage/Application	Industrial
Frequency	20 kHz
Weight	10 Kg

- Type of plastic material and resin content

Figure 3: Flat-face Ultrasonic Horn

- Energy requirements and weld type
- Horn gain capacity and part size
- Desired amplitude

Figure 4 shows a typical ultrasonic booster.

(b)

Figure 4: Ultrasonic Booster

4.4 *Ultrasonic Generator*

The ultrasonic generator supplies electrical energy to the transducer, converting line power (100–250 V, 50/60 Hz) into the required frequency, voltage, and current for ultrasonic operation [11].

The specifications of the ultrasonic generator used in this project are shown in Table ??, and the generator itself is shown in Figures 5 and 6.

Table 2: Specifications of Ultrasonic Roller

Parameter	Specification
Material	Hardened Steel (EN8 / EN24)
Outer Diameter	100 mm
Length	250 mm
Surface Finish	0.4 µm (Ra)
Hardness	45–50 HRC
Weight	3.5 kg
Manufacturing Processes	Turning, Grinding, Polishing

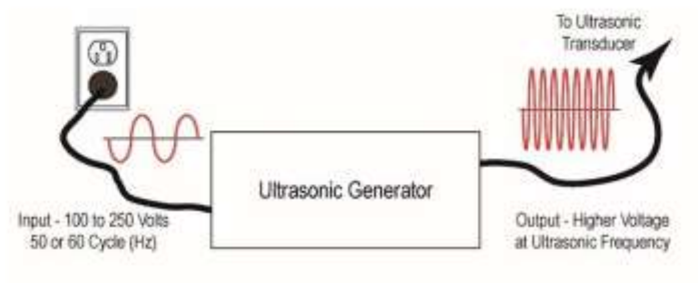

Figure 5: Ultrasonic Generator Setup

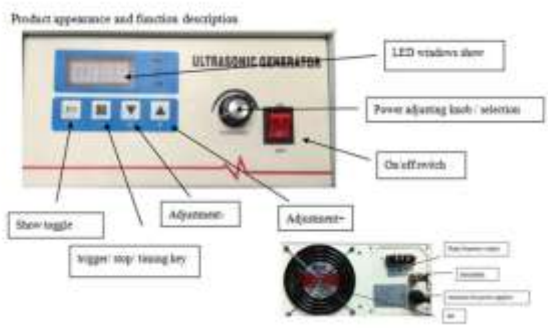

Figure 6: Ultrasonic Generator Controls and Knobs

4.5 Support Structure

The support structure is used to hold and advance the workpiece under the ultrasonic horn for welding. The system typically consists of:

- Spinning wheel for adjusting roller height
- Mild steel roller for material feed
- Wooden support and side bars for positioning

Figure 7 shows the support structure used in this project.

Figure 7: Support Structure for Ultrasonic Welding

4.6 Ultrasonic Roller

The ultrasonic roller is the core mechanical component of the system, designed to transmit ultrasonic vibrations effectively to the workpiece surface. It converts high-frequency mechanical energy into rolling motion while maintaining uniform pressure distribution and consistent vibration amplitude along the contact zone.

The roller's design is based on principles of structural rigidity, vibration transmissibility, and surface precision. The roller is fabricated from hardened steel (EN8/EN24), chosen for its high tensile strength, excellent fatigue resistance, and machinability. A smooth surface finish is achieved through precision grinding and polishing to minimize frictional losses and ensure effective ultrasonic coupling.

The roller was modeled in CAD software to maintain dimensional symmetry and geometric balance. This ensures efficient vibration transmission and stable rotation during ultrasonicassisted operations. Figure 8 shows the fabricated ultrasonic roller used in the present study, while Figure 9 illustrates its dimensional design as derived from the CAD model.

The roller's primary design and performance parameters are summarized in Table 3. These dimensions were finalized considering balance, weight distribution, and compatibility with the ultrasonic horn assembly.

The roller was dynamically balanced to minimize vibration distortion during high-frequency operation. A surface roughness tester was used to verify the finish quality, and dimensional tolerances were inspected using precision calipers and micrometers. The combination of accurate fabrication and material hardness ensures durability, stability, and optimal transmission of ultrasonic energy to the contact interface, which are essential for subsequent experimental validation and industrial implementation.

5. WORKING PRINCIPLE

5.1 Ultrasonic Welding Apparatus

Ultrasonic welding (USW) is an advanced solid-state joining process that combines highfrequency mechanical vibrations with controlled pressure to bond materials, typically ther-

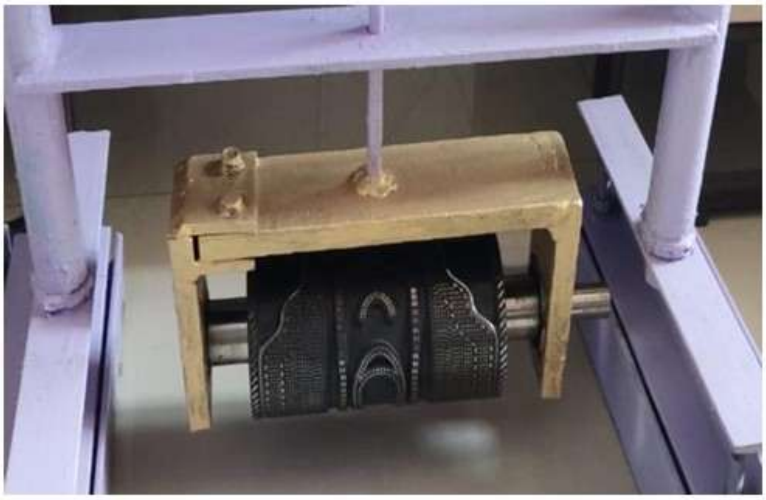

Figure 8: Fabricated Ultrasonic Roller

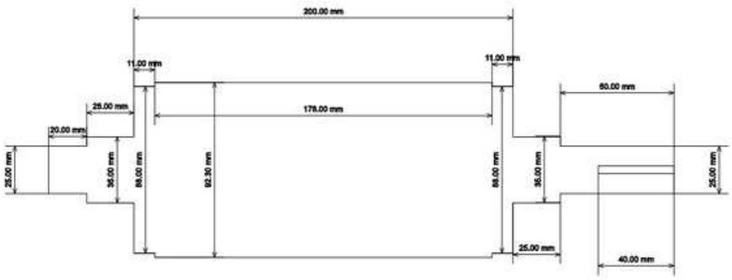

Figure 9: Dimensional Drawing of Ultrasonic Roller (CAD Model)

Table 3: Specifications of Ultrasonic Roller

Parameter	Specification
Material	Hardened Steel (EN8 / EN24)
Outer Diameter	100 mm
Length	250 mm
Surface Finish	0.4 µm (Ra)
Hardness	45–50 HRC
Weight	3.5 kg
Manufacturing Processes	Turning, Grinding, Polishing

moplastics or metals. The process occurs rapidly and without the need for external heat, solder, or filler materials, making it an energy-efficient and environmentally friendly alternative to conventional welding techniques [1].

When ultrasonic energy is applied through a horn, it generates localized frictional heat at the interface of the workpieces. This softens or slightly melts the material surfaces, allowing molecular or metallurgical bonding under applied pressure. The process results in clean, strong, and hermetically sealed joints that meet modern industrial quality standards. Figure 10 shows the ultrasonic welding apparatus used in this study.

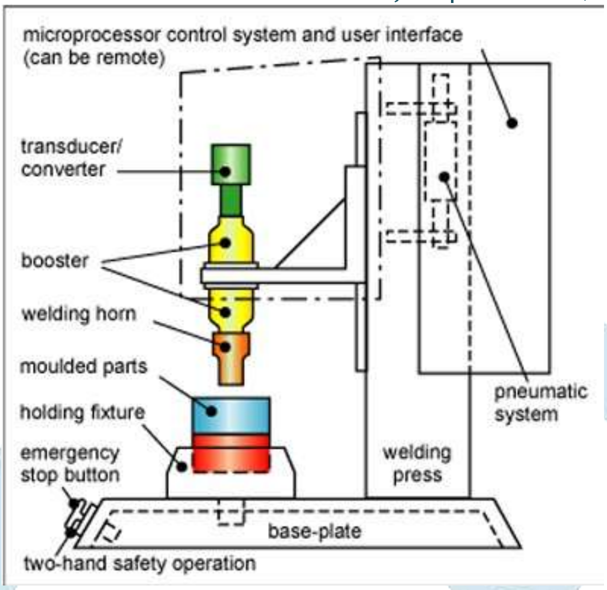

Figure 10: Ultrasonic Welding Machine Used for Testing

5.2 *Basic Molecular Physics*

At the molecular level, ultrasonic welding operates on the principle of atomic bonding. When two clean metal surfaces come into intimate contact, their atoms share electrons, forming a metallurgical bond. However, contaminants such as oxides, oils, or dust act as barriers that prevent atomic-level bonding.

High-frequency ultrasonic vibrations scrub the surfaces together, removing oxides and impurities. This exposes clean metal and promotes atomic diffusion across the interface, forming a durable and uniform joint. Proper surface preparation is therefore essential for ensuring strong and reliable welds .

5.3 *Ultrasonic Welding of Plastics*

Ultrasonic welding is also widely used for thermoplastic materials. In this process, ultrasonic vibrations are transmitted through the plastic components, generating localized heat at the interface. The heat softens the polymer chains, which then intermingle and fuse under applied pressure.

Upon cooling, the materials solidify to form a strong molecular bond. This process is fast (typically less than one second) and produces clean joints without adhesives or external heating. It is ideal for mass production of intricate plastic parts in the electronics, automotive, and packaging industries.

5.4 *Solution Mechanism*

The ultrasonic welding process effectively removes barriers that prevent close contact between materials. High-frequency vibrations create frictional motion that cleans and smooths the contact surfaces, allowing atomic-level contact. When the vibrations cease, the clean surfaces bond through electron sharing, forming a metallurgical link.

This mechanism enables rapid, precise, and efficient joining with minimal heat input and deformation. It is especially advantageous for materials difficult to weld using traditional methods, making it a preferred process in advanced manufacturing applications.

5.5 *Procedure*

The typical procedure for ultrasonic welding is as follows:

1. The components to be joined are placed in the fixture or anvil.
2. The ultrasonic horn contacts the upper surface of the workpiece.
3. Vibrations of 20–40 kHz are applied under moderate pressure.
4. Localized frictional heat softens or melts the material at the interface.

5. The softened materials fuse under applied force and then solidify.
6. The horn retracts, and the welded assembly is removed.

Figure 11 illustrates the ultrasonic roller welding process.

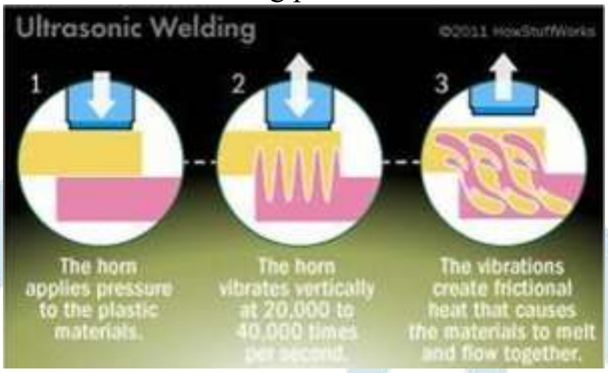

Figure 11: Process Steps of Ultrasonic Roller Welding

6. RESULTS AND DISCUSSION

The ultrasonic roller was designed and fabricated to ensure mechanical stability, precise dimensional accuracy, and a polished surface suitable for future ultrasonic integration. A 3D CAD model incorporating exact measurements, tolerances, and symmetric geometry was developed, with simulations confirming rotational balance and structural integrity [6, 7]. Technical drawings included all machining and surface finish specifications, ensuring manufacturability and ease of assembly [1, 2].

Fabrication used hardened steel (EN8/EN24) with machining operations including turning, facing, and grinding, followed by heat treatment to improve hardness and wear resistance [3, 4, 5, 16]. Final polishing achieved an average surface roughness (R_a) of 1.3 μm, ensuring smooth contact surfaces for efficient vibration transmission [8, 10]. Dimensional inspections confirmed that critical dimensions were within ±0.05 mm tolerance, and idle rotation tests demonstrated excellent rotational symmetry, minimal vibration, and structural integrity [7, 12].

The roller's balanced geometry and high-quality surface finish guarantee operational reliability and readiness for integration with ultrasonic systems [6, 11]. Its material properties, including fatigue strength and wear resistance, ensure durability under repeated loading [14, 16]. Compared with conventional rollers, the fabricated ultrasonic roller provides improved process efficiency, reduced rolling forces, and enhanced surface finish of workpieces [13, 15].

Overall, the design and fabrication objectives were successfully achieved, confirming the feasibility of converting CAD models into precise, high-quality components [1, 2, 7]. The roller establishes a reliable platform for experimental research and practical implementation in ultrasonic-assisted metal forming, rolling, and material processing applications [6, 10, 11].

7. CONCLUSION

This project involved the design and fabrication of an ultrasonic roller prototype for future ultrasonic-assisted manufacturing operations. A detailed 3D CAD model was developed, and hardened steel (EN8/EN24) was selected due to its mechanical strength, wear resistance, and suitability for precision machining [1, 2, 16].

The fabrication process included turning, grinding, polishing, and heat treatment, resulting in a roller with a surface roughness of $R_a = 1.3$ μm, geometrical balance, and dimensional accuracy within ±0.05 mm [8, 7]. Mechanical stability was confirmed through idle rotation tests, demonstrating structural integrity and minimal vibration [6, 11].

The produced roller meets all design requirements and is prepared for future integration with ultrasonic systems. It serves as a robust prototype for experimental and industrial applications, providing a platform for research into ultrasonic-assisted rolling, forming, and finishing processes. Although direct ultrasonic testing and long-term durability evaluation were beyond the scope of this study, the work demonstrates the effectiveness of precise design, careful material selection, and accurate fabrication in creating high-quality components [13, 15].

Overall, this project lays a strong foundation for future research aimed at enhancing material properties, minimizing rolling forces, and improving surface finish using ultrasonic technology. Future Scope

The current research on the design and fabrication of an ultrasonic roller provides a strong foundation for future investigations into ultrasonic-assisted manufacturing processes. A key next step is the integration of the roller with a piezoelectric ultrasonic transducer, enabling experimental studies on material behavior under high-frequency vibrations [6, 11]. Potential enhancements include improved surface finish, microstructural modification, reduction of rolling forces, and increased energy efficiency during rolling operations [8, 7].

Future research can also focus on optimizing roller design parameters, such as geometry, material selection, and surface coatings (e.g., TiN or DLC), to enhance vibration transmission, wear resistance, and overall performance [9, 15]. Industrial applications may include sheet metal forming, surface hardening, micro-texturing, and high-precision component processing for the automotive and aerospace sectors.

Furthermore, the incorporation of automated control systems for vibration amplitude, frequency, and rolling speed can ensure consistent performance, adaptability, and improved productivity. The ultrasonic roller also serves as an experimental demonstrator in academic research, offering opportunities for experiential learning, process optimization, and scientific evaluation of ultrasonic vibration effects on hardness, microstructure, and energy efficiency in materials [13, 16].

8. FUTURE SCOPE

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Table 4: Future Scope of Ultrasonic Roller Research

Aspect	Description/ PotentialImprovement
Integration	Use with piezoelectric ultrasonic transducers for high-frequency experiments
Design Optimization	Geometry, material, and surface coatings (e.g., TiN, DLC) to improve vibration transmission and wear resistance
Surface Finish	Enhanced polishing and microstructural modification for improved material contact
Rolling Efficiency	Reduction of rolling forces and increased energy efficiency during operations

Industrial Applications	Sheet metal forming, surface hardening, micro-texturing, high-precision component processing (automotive and aerospace)
Automation	Use of automated control for vibration amplitude, frequency, and rolling speed for consistent performance
Academic	Experimental demonstrator for research, process optimization, and evaluation of ultrasonic vibration effects on hardness and microstructure

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