

Advances in Robot-Assisted Abrasive Polishing for Precision Manufacturing

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Abstract - The increasing demand for high-precision components has created a need for reliable and consistent surface finishing processes. Conventional manual polishing is labor intensive, operator dependent, and difficult to apply uniformly to complex surfaces. Robot-assisted abrasive polishing provides an effective alternative by combining robotic motion control with controlled abrasive material removal, offering improved repeatability, flexibility, and surface quality. This review presents the working principles, major technologies, advantages, and limitations of robot-assisted abrasive polishing for precision manufacturing. Different polishing approaches and the influence of important process conditions on surface finishing are discussed. The review also highlights key challenges, including tool wear, abrasive degradation, robot stiffness, surface curvature, and maintaining consistent contact conditions. Future developments in adaptive force control, machine-vision-assisted inspection, real-time process monitoring, digital-twin simulation, and AI-based optimization are discussed. The integration of these technologies can support the development of flexible, intelligent, and automated polishing systems for advanced precision manufacturing.

Key Words: Robot-assisted polishing, Abrasive polishing, Workpiece surfaces, Precision manufacturing, Flexible polishing, Magnetorheological polishing, Surface finishing,

1. INTRODUCTION

In advanced manufacturing and precision engineering, the surface integrity of mechanical components plays an important role in product performance, dimensional accuracy, wear resistance, fatigue life, and functional reliability. Surface roughness, residual stresses, microhardness, and surface defects directly influence the performance of components used in aerospace, automotive, biomedical, optical, and die and mold applications.

Conventional machining processes such as turning, milling, and grinding are effective for shaping components; however, they may not always achieve the required fine surface finish. Therefore, polishing is commonly used as a final finishing operation to remove machining marks, scratches, and microscopic surface irregularities.

Traditional manual polishing depends heavily on operator skill and is associated with low repeatability, inconsistent surface quality, high labor effort, and limited suitability for complex geometries. Robot-assisted abrasive polishing overcomes these limitations by providing automated tool movement, repeatable trajectories, and improved control of process variables such as tool speed, feed rate, contact path, and abrasive grade.

2. WORKING PRINCIPLE OF ROBOT-ASSISTED ABRASIVE POLISHING

Robot-assisted abrasive polishing is a surface finishing process in which an industrial robot manipulates a polishing tool along a predefined path while maintaining controlled interaction between the abrasive medium and the workpiece.

The rotary abrasive tool consists of a backing pad and abrasive discs of different grit sizes. During polishing, the rotating disc contacts the workpiece surface and removes microscopic asperities through micro-cutting, micro-ploughing, and rubbing actions. The finishing quality depends on spindle speed, feed rate, abrasive grade, contact conditions, and tool stability.

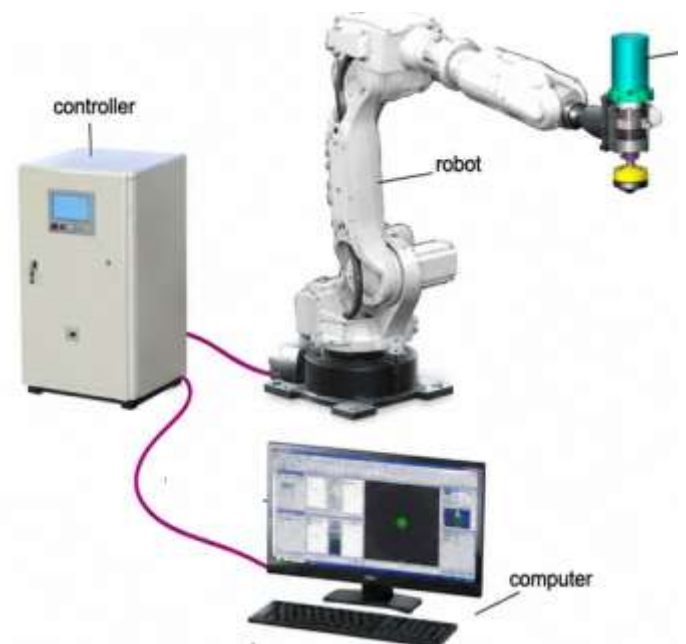


Fig -1: Schematic diagram of a robot-assisted abrasive polishing system



Fig -2: Rotary abrasive polishing tool

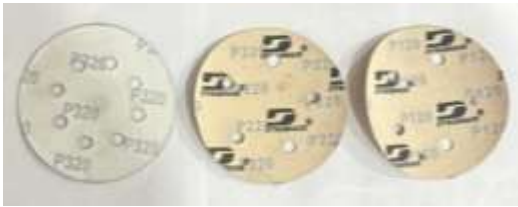


Fig -3: Abrasive polishing discs

Spindle speed determines the relative velocity between the abrasive particles and workpiece surface. Feed rate controls the contact duration between the tool and workpiece. Abrasive grade determines particle size and cutting ability. A proper balance of these parameters is necessary to achieve low surface roughness without excessive material removal or surface damage.

3. ABRASIVE POLISHING TECHNOLOGIES

Several Several abrasive polishing technologies are used in precision manufacturing depending on workpiece material, geometry, required surface finish, and production requirements. These methods may be conventional, flexible, magnetic, chemical, or robot-assisted in nature.

Conventional polishing uses abrasive papers, polishing cloths, pastes, and manually operated tools. It is simple and economical but depends strongly on operator skill and often produces inconsistent results on complex surfaces.



Fig -4: Conventional Polishing

Abrasive Flow Machining uses a semi-solid abrasive medium forced through or across a workpiece surface. It is suitable for internal passages and difficult-to-access regions but requires specialized equipment and offers limited local control.



Fig -5: Abrasive Flow Machining

Magnetic Abrasive Finishing uses magnetic fields to control abrasive particles and form a flexible abrasive brush. It can produce fine surface finishes but is often limited by material compatibility, component size, and equipment complexity.



Fig -6: Magnetic Abrasive Finishing

Chemical Mechanical Polishing combines chemical reaction and mechanical abrasion to produce ultra-smooth surfaces. It is widely used in semiconductor and optical applications but involves chemical handling, process control challenges, and higher cost.



Fig -7: Chemical Mechanical Polishing

Elastic Emission Machining is an ultra-precision process capable of atomic-level material removal. Although it can produce extremely low roughness, it generally has low material removal rate and requires specialized equipment.



Fig -8: Elastic Emission Machining

Robot-assisted polishing combines abrasive finishing with robotic automation. It improves repeatability, reduces manual

dependency, and enables controlled polishing of curved and complex geometries.



Fig -9: Robot-Assisted Abrasive Polishing

Rotary abrasive disc polishing uses a rotating abrasive disc attached to a backing pad. In robotic applications, the robot controls the tool path while the rotating disc performs material removal. This method is suitable for aluminium alloy specimens and can be optimized through DOE techniques.



Fig -10: Robot-Assisted Abrasive Polishing

4. CHALLENGES AND FUTURE RESEARCH

Despite the advantages of robot-assisted abrasive polishing, several technical challenges must be addressed for wider industrial adoption. The process is affected by tool wear, abrasive degradation, robot stiffness limitations, variation in surface curvature, and difficulty in maintaining constant polishing force. Small deviations in force, feed path, or tool contact can lead to non-uniform material removal and variations in final surface roughness.

Parameter optimization is another important challenge because abrasive polishing involves complex interactions among spindle speed, feed rate, abrasive grit size, contact pressure, tool condition, and material behavior. Process monitoring is also difficult because surface quality is usually measured after polishing rather than during operation.

Future research should focus on intelligent robotic polishing systems with adaptive force control, machine vision assisted inspection, real-time surface roughness prediction, digital twin simulation, and AI-based parameter optimization. Hybrid polishing technologies combining abrasive polishing with magnetic, ultrasonic, or compliant tool systems may further improve surface finish and material removal efficiency. Integration of Industry 4.0 frameworks can enable closed-loop, data-driven, and autonomous polishing systems for precision manufacturing applications.

5. CONCLUSIONS

Robot-assisted abrasive polishing is a promising surface-finishing technology for precision manufacturing because it combines robotic flexibility and repeatability with controlled abrasive material removal. The review shows that robotic polishing can reduce operator dependency, improve surface consistency, and provide better control when finishing complex and curved geometries. Different polishing technologies offer different capabilities depending on workpiece material, geometry, required surface finish, and production requirements. Robot-assisted polishing provides a flexible approach for automated finishing and is particularly suitable for precision components and complex surfaces. The overall polishing performance is influenced by process parameters, tool wear, abrasive degradation, robot stiffness, surface curvature, contact force, and tool-workpiece interaction. Proper control of these factors is essential for achieving uniform material removal and improved surface quality. Despite its advantages, wider industrial implementation requires improved control of force, tool condition, and surface quality. Future research should focus on adaptive force control, machine-vision-assisted inspection, real-time process monitoring, digital-twin simulation, and intelligent optimization. Integration with Industry 4.0 technologies can support closed-loop and autonomous polishing systems.

Overall, robot-assisted abrasive polishing has considerable potential to provide repeatable, flexible, and high-quality surface finishing for precision manufacturing. Continued development of sensing, adaptive control, process modelling, and intelligent automation will be important for achieving more efficient and autonomous polishing operations.

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