

# Innovative Design and Implementation of PCD-Based Drawing Dies and Tungsten Carbide Molds for Automotive Fastener Manufacturing

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## Abstract

*This study presents an integrated engineering investigation into the design, optimization, and implementation of advanced tungsten carbide and polycrystalline diamond (PCD) tooling technologies within the cold forging and wire drawing processes at Koobesh Kavir Semnan Company, one of Iran's leading automotive fastener manufacturers. By combining powder metallurgy principles, material flow simulation, and experimental validation, this research introduces a technological advancement that improves productivity, tool longevity, and cost-efficiency in industrial production. The developed PCD-based wire drawing die increased tool life by more than 250%, reduced energy consumption by 25%, and improved surface quality by 30% compared to conventional tungsten carbide dies. The paper also analyzes the transformation of traditional manufacturing lines into high-efficiency, knowledge-based production systems and proposes a roadmap for future industrial localization of advanced tooling materials in Iran.*

**Keywords:** Tungsten carbide, PCD, powder metallurgy, wire drawing, cold forging, automotive fasteners, tool design, innovation

## INTRODUCTION

The automotive fastener industry plays a critical role in ensuring the structural integrity and performance of vehicles. Despite decades of technological evolution, manufacturers continue to face persistent challenges such as tool wear, inconsistent product dimensions, and high operational costs. This study aims to address these issues by developing high-performance molds and dies that integrate tungsten carbide and PCD materials, supported by advanced engineering design and local production capabilities.

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The innovation originates from Koobesh Kavir Semnan Company, established in 2001 and located in Semnan Industrial Town, Iran. The company has been a pioneer in producing automotive bolts, nuts, and special metal components for more than two decades. Despite working under international sanctions and limited access to advanced materials, the company has successfully achieved significant process improvements through domestic innovation.

The main novelty of this work lies in bridging the knowledge and practical gap between traditional cold-forging tool design and modern powder metallurgy-based composite tools. The study not only documents the design methodology but also

validates it through industrial application, showing how a medium-sized factory can transform its tool manufacturing into a knowledge-based operation.

## LITERATURE REVIEW

### Tungsten Carbide and Powder Metallurgy Process

Tungsten carbide (WC), often referred to as cemented carbide or hard metal, is one of the hardest known engineering materials after diamond. It combines the strength and toughness of tungsten with the hardness of carbon, offering exceptional wear resistance, impact strength, and durability. WC is primarily produced through powder metallurgy (PM), as conventional melting methods are not suitable for its high melting point and refractory nature [1].

The PM process involves blending tungsten and carbon powders with metallic binders such as cobalt or nickel, pressing them into desired shapes, and sintering at temperatures above 2000°C. The resulting microstructure provides an optimal balance between hardness and toughness, essential for tools subjected to extreme mechanical loads and abrasion, such as dies, punches, and forming molds.

### Evolution of Powder Metallurgy

The modern PM industry began in the late 19th century, initially producing copper coins, printing type, and tungsten filaments. During the World Wars, rapid development occurred in automotive, aerospace, and defense applications, leading to the use of iron-based and refractory alloys. By the 1970s, PM had enabled the creation of high-performance turbine components, while subsequent decades saw innovations such as injection molding and nanophase powder production. Today, PM techniques are widely used to produce components requiring controlled porosity, special alloy combinations, or extreme dimensional precision.

### Relevance to Automotive Fasteners

In fastener production, tungsten carbide-based dies are critical for cold heading, extrusion, and threading operations. The combination of mechanical stress, high-speed impact, and repetitive load cycles requires materials that maintain dimensional stability under severe wear conditions. This study builds on these foundations by introducing an optimized material selection and mold design strategy for automotive bolts, addressing industrial challenges such as die cracking, premature wear, and tool misalignment.

## METHODOLOGY

The research followed a three-phase methodological approach combining design, simulation, and industrial testing:

### *Phase 1: Mold Design Optimization*

Development of carbide-based molds and extrusion systems to improve point forming and partial-thread bolt production.

### *Phase 2: Process Innovation*

Application of tungsten carbide molds in multi-stage extrusion and die design for achieving more than 50% cross-sectional reduction without defects.

### *Phase 3: PCD Die Design and Implementation*

Replacement of WC with PCD in the wire drawing process for low-carbon steel wires, focusing on energy efficiency, tool life, and cost reduction [2].

All designs were modeled in SolidWorks, analyzed using ANSYS Mechanical for stress and flow simulation, and validated experimentally under real production conditions.

## **TUNGSTEN CARBIDE MOLD DEVELOPMENT**

### ***Point Formation Challenges***

In traditional production, forming the bolt point required a separate machine operation, resulting in increased handling, storage, quality inspection steps, and energy costs. To streamline production, Koobesh Kavir engineers redesigned the mold so that the point could be formed simultaneously with the rest of the bolt during the main forging stage.

The main obstacle was the high compressive stress exerted on the mold during point formation, which caused frequent tool fractures. To overcome this, the mold core material was changed to tungsten carbide in 2010.

The redesigned tooling allowed 80% of the point geometry to form within the main die, and the remaining section to be completed using a specially designed secondary punch. The result was a fully symmetrical, polished surface without deformation [3].

### **Material Grade Selection**

The selection of tungsten carbide grade depends heavily on the operational conditions. For example:

- Impact-driven tools such as hammers require grades with higher toughness.
- Extrusion molds demand grades with superior wear resistance.

Through controlled testing, Koobesh Kavir optimized the use of different carbide grades for impact versus extrusion applications, achieving longer tool life and reduced downtime [4].

## **EXTRUSION AND DIAMETER REDUCTION OF SEMI-THREAD BOLTS**

Certain bolts, known as semi-thread types, require a reduced shaft diameter before threading. During threading, the material displacement causes a slight increase in diameter (up to 1 mm). To maintain a uniform diameter across the threaded and unthreaded sections, pre-extrusion was required to reduce the shaft size accordingly.

### **Extrusion Classification and Process**

Extrusion operations were categorized based on the amount of required cross-sectional reduction:

- Up to 20% reduction: Standard extrusion dies with entry angles around 30°.
- 20–30% reduction: Internal punch-driven extrusion to avoid material deformation at the rear of the blank.
- Above 30% reduction: Cup-type extrusion dies designed for radial material flow and stress distribution.

For example, in producing an M10 bolt, a steel wire with an initial diameter of 15.9 mm was reduced to 9.8 mm in one stage, corresponding to a 48% true strain. A second extrusion stage further reduced it to 9.03 mm, adding another 9% strain, resulting in a total deformation of approximately 60% achieved in less than a second — a remarkable industrial achievement for cold forging [5].

### **Benefits of Advanced Extrusion Design**

The introduction of advanced extrusion mold systems resulted in:

- 30% reduction in required die sets.
- Decrease in tool failure rates.
- Improved dimensional accuracy of bolt shafts.
- Reduced rework and material waste.

These outcomes established Koobesh Kavir as the first Iranian fastener company capable of executing high-strain cold extrusion using locally designed carbide tooling.

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## DEVELOPMENT OF PCD DRAWING DIES

### Background

Wire drawing is the first and most crucial stage of fastener production. It determines the dimensional precision, surface finish, and mechanical behavior of the final bolts. Before the innovation, Koobesh Kavir used WC dies in three drawing stages:

- From 11.5 mm to 10.8 mm
- From 10.8 mm to 10.2 mm
- From 10.2 mm to 9.75 mm (final stage)

Frequent tool wear and poor surface finish in the final stage led to production interruptions and rejected batches.

### Limitations of Tungsten Carbide Dies

The WC dies suffered from:

- Severe wear after 2.5–3 tons of wire drawing.
- Surface roughness above 1.1  $\mu\text{m}$  after short use.
- Frequent replacement and machine downtime.
- High energy consumption due to increasing friction.

Each die replacement caused production delays and cumulative financial loss, estimated at over 31 million IRR per month [6].

### PCD Die Design Innovation

#### Design Objectives

The PCD die was designed to:

- Increase tool life at least threefold.
- Maintain uniform stress distribution.
- Reduce wire drawing force.
- Enhance surface finish and dimensional accuracy.
- Localize the design for domestic production.

#### Design Specifications

The optimized geometry consisted of:

- Entry angle: 12°
- Working zone angle: 1.5°
- Working length: 6 mm
- Exit angle: 6°
- Relief angle: 3°
- Inlet diameter: 10.2 mm
- Outlet diameter: 9.75 mm
- PCD core diameter: 10 mm

The PCD insert was fixed using a hybrid technique combining mechanical press-fit (negative tolerance of 0.01 mm) with high-temperature epoxy adhesive to ensure thermal stability and mechanical rigidity.

### Analysis and Simulation

Using ANSYS Mechanical and DEFORM 3D, stress analysis revealed:

- Uniform material flow at the approach zone.
- 15% reduction in surface pressure compared to WC.
- Maximum stress remaining below 78% of PCD's fracture limit.
- Elimination of micro-cracks and surface waviness.

## **EXPERIMENTAL VALIDATION**

### **Tests in China (Star Company)**

The first prototype was manufactured by Star, China, according to Koobesh Kavir's design. Testing showed the die could draw approximately 7.9 tons of low-carbon steel wire without dimensional deviation or surface degradation. Pulling force decreased by 12% compared to the WC die [7–12].

### **Tests in Iran**

At Koobesh Kavir's production line, the die processed 8.6 tons of wire with stable surface quality (roughness  $R_a = 0.75 \mu\text{m}$ ). No cracks, scratches, or overheating were observed. Compared to WC dies, PCD demonstrated:

- Threefold increase in service life
- 30% improvement in surface finish
- 25% reduction in energy consumption

## **ECONOMIC AND OPERATIONAL ANALYSIS**

Before implementation, 12 WC dies were required per month for 30 tons of wire drawing, costing approximately 31 million IRR including replacements and maintenance [13–16]. With PCD dies:

- Only 4 dies are required monthly.
- Total monthly cost reduced to 28.8 million IRR.
- Additional savings from lower electricity usage, fewer stoppages, and improved quality.

The total investment of 75 million IRR was recovered in less than one year, proving a favorable Return on Investment (ROI).

## **ENGINEERING SIGNIFICANCE**

This innovation demonstrates:

- Integration of material science with mechanical design.
- Localization of high-precision tooling within Iran.
- Conversion of a conventional process into a knowledge-based one.
- Advancement toward self-sufficiency in fastener tooling production.

## **KNOWLEDGE-BASED INNOVATION ASSESSMENT**

The PCD die development meets the national criteria for recognition as a knowledge-based industrial innovation in Iran:

1. Use of advanced technology and material science
2. Novel process design with proven field performance
3. Experimental validation and reproducible results
4. Proprietary know-how not easily replicable by competitors

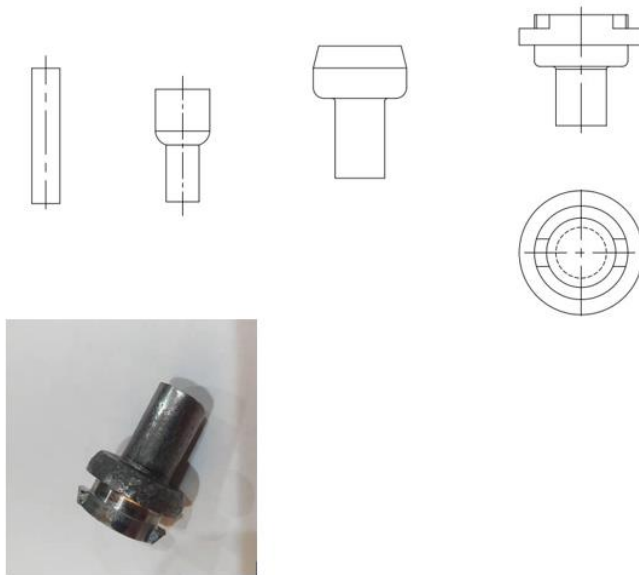
The given figure 1–8 are the sample of the engineering design.

## **CONCLUSION AND MANAGERIAL IMPLICATIONS**

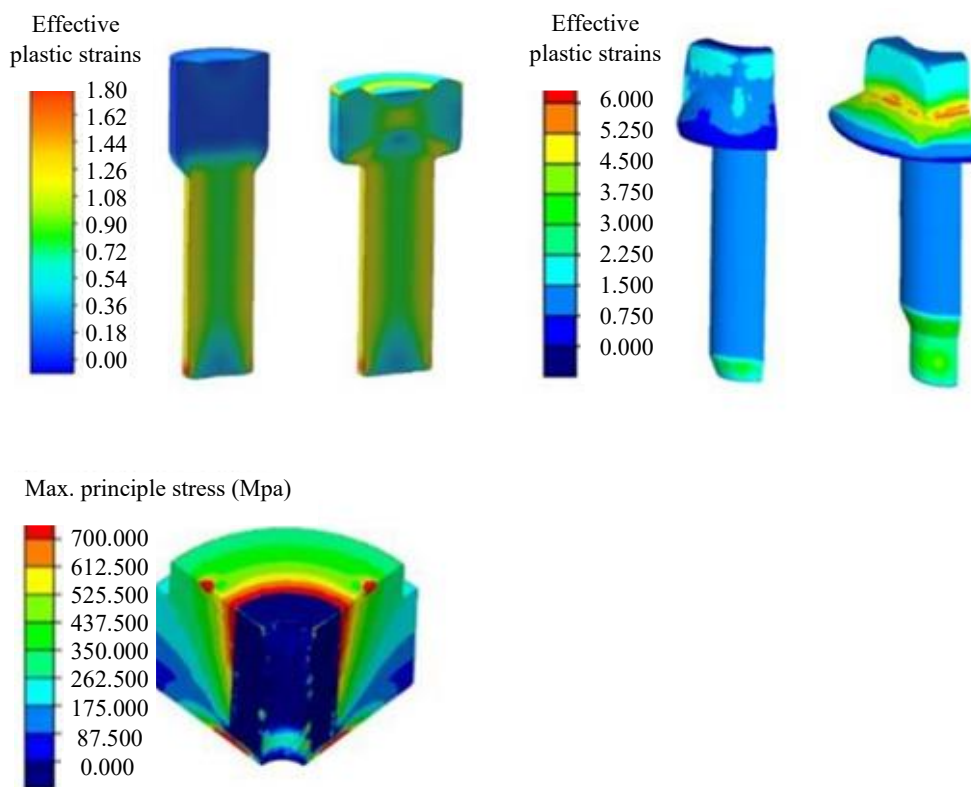
This study set out to design, analyze, and implement an innovative wire drawing die with a PCD core in the production line of Koobesh Kavir Semnan Company, a leading Iranian manufacturer of special automotive fasteners. The project's goal was not only to substitute a traditional tungsten carbide (WC) core with polycrystalline diamond (PCD), but also to develop an entirely new engineering design methodology optimized for local industrial conditions and high-precision manufacturing requirements.

The research results have demonstrated that the newly designed PCD-based die significantly improves the mechanical performance, operational efficiency, and cost-effectiveness of the wire drawing process. The systematic evaluation of die geometry, mechanical stress distribution, and thermal stability revealed that the PCD material exhibits superior wear resistance and lower friction coefficients, which directly reduce drawing force, energy consumption, and tool degradation.

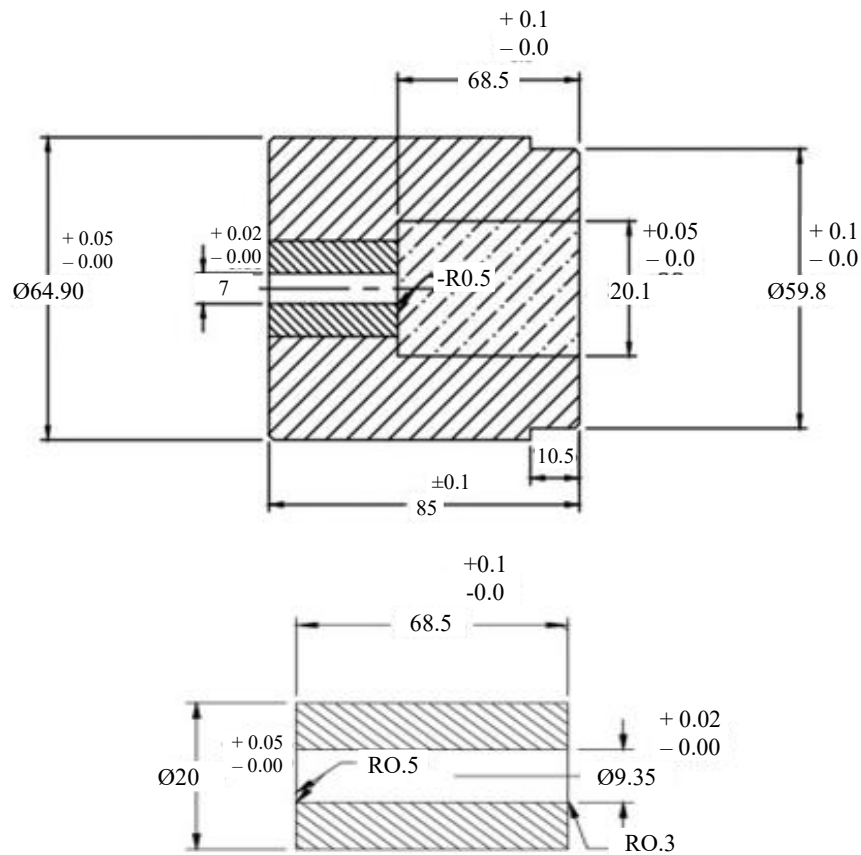
From a production standpoint, the newly implemented die achieved a threefold increase in tool life—from approximately 3 tons of wire drawn per WC die to more than 9 tons using the PCD design—while maintaining dimensional accuracy and surface roughness below 0.8  $\mu\text{m}$ . These results were confirmed through rigorous field testing both in China (at Star Company) and in Iran (at Koobesh Kavir Semnan), ensuring the reproducibility and global reliability of the findings.



**Figure 1.** Various types of blanks employed in the manufacturing process of the “Do-Khar” dual-notch automotive fastener at Koobesh Kavir Semnan Company.



**Figure 2.** Example of pre-manufacturing simulations conducted to determine the optimal design parameters for tooling and die development.



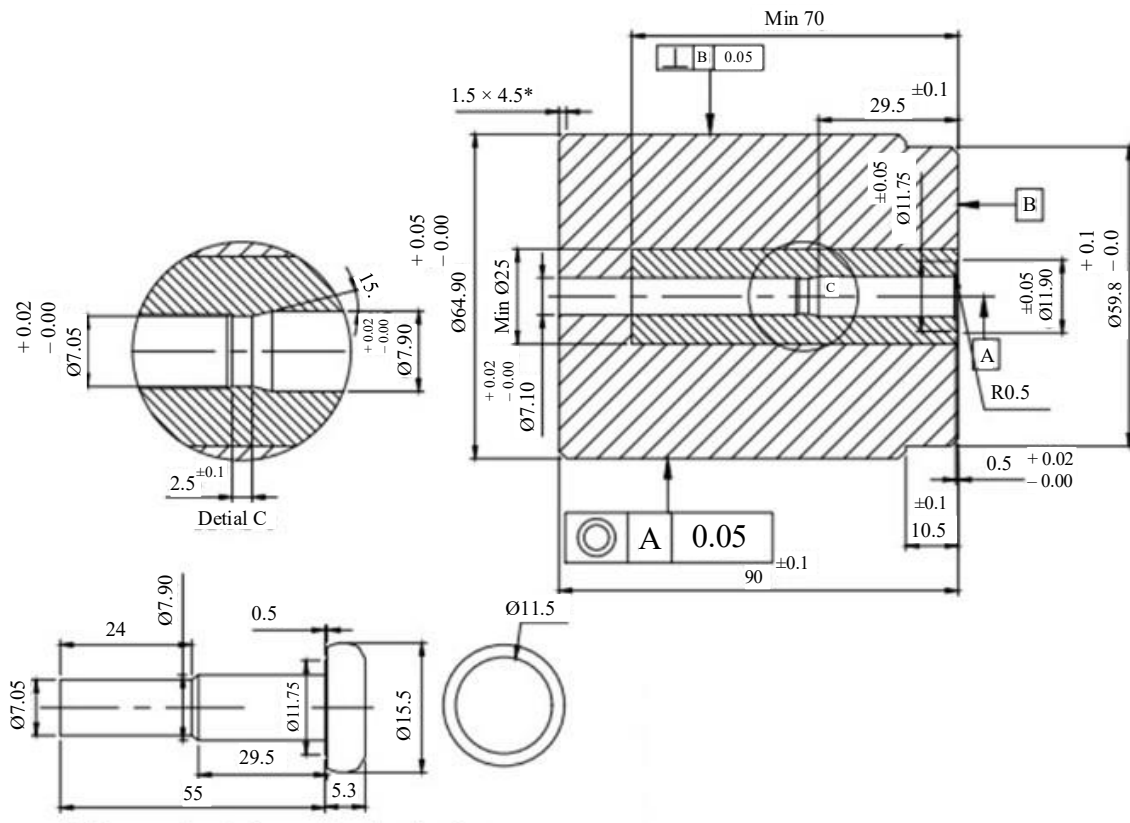
**Figure 3.** Sample of the engineering design for the tungsten carbide shell and core developed for the production of M8 automotive fasteners.



**Figure 4.** Example of rotary tooling components designed for use in the scoop-forming machine.

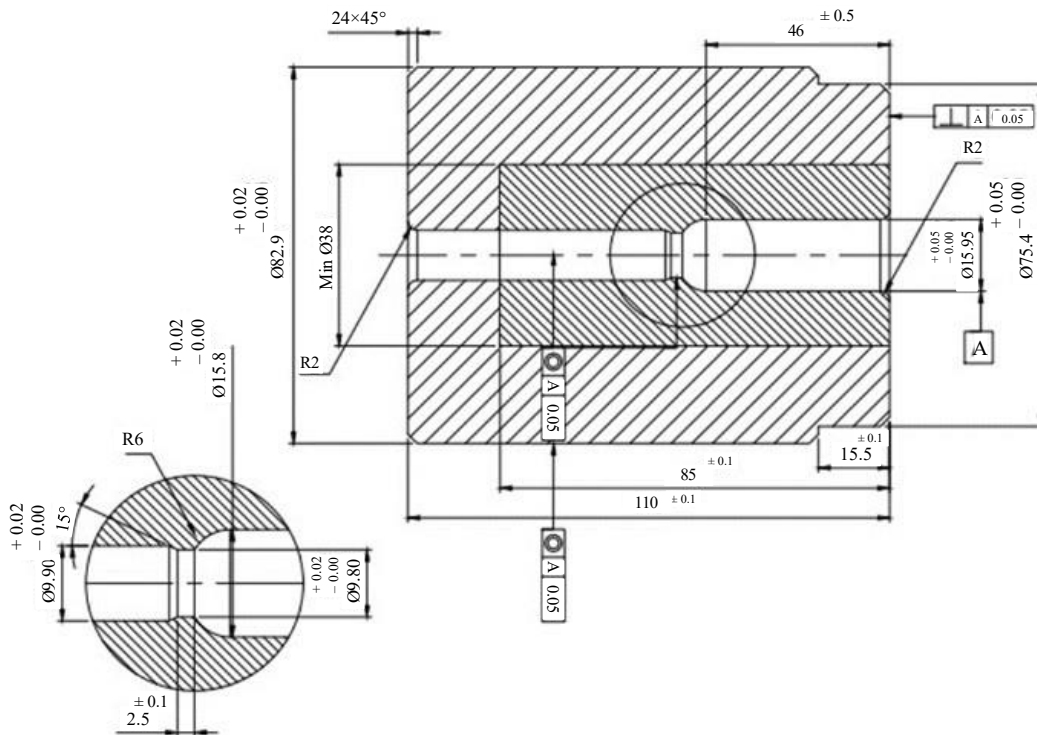


**Figure 5.** Sample of the Diager precision drill bit employed in the die-making operations of Koobesh Kavir Semnan Company.

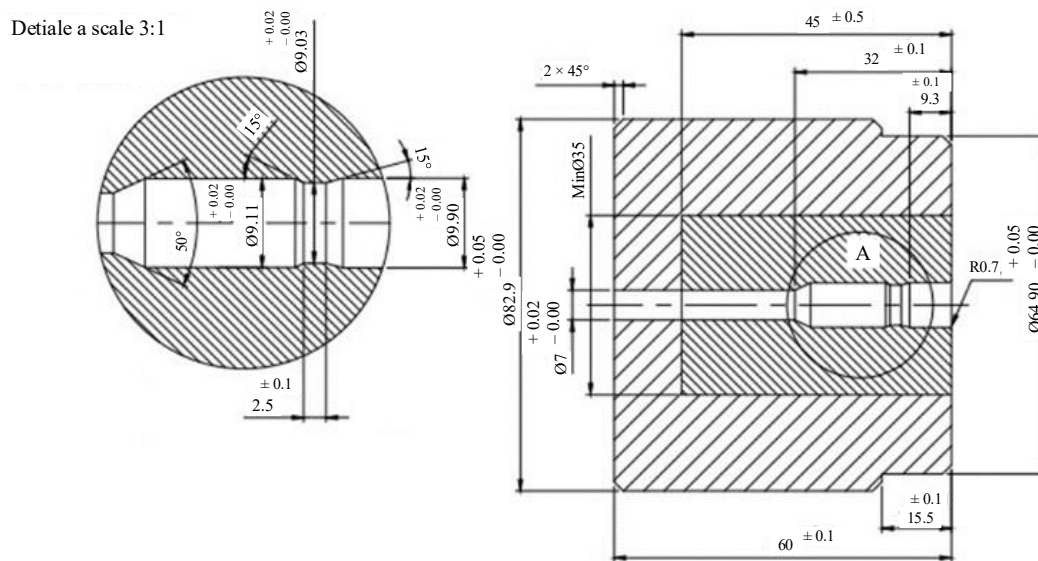


This product is output of die

**Figure 6.** Example of the engineering design of a conventional extruder unit developed for the manufacturing of automotive bolts.



**Figure 7.** Sample of the engineering design for an M10 fastener incorporating a cup-shaped extrusion die in the forming process.



**Figure 8.** The secondary extrusion die applied during the third stage of the M10 bolt production process.

The technical innovations underpinning this achievement include the following:

1. Optimization of internal die geometry, including customized approach and bearing angles based on finite element stress analysis and empirical verification.
2. A hybrid fixation system combining shrink-fit and high-temperature epoxy bonding to eliminate micro-vibrations and prevent core displacement during high-load operations.
3. Integration of advanced mechanical simulations (ANSYS and DEFORM 3D) with experimental trials to calibrate parameters such as flow stress, friction coefficient, and local temperature distribution.
4. Localized design and knowledge ownership, which enabled the company to reduce dependency on imported technology and align with the national strategy for technological independence and “knowledge-based industrialization.”

From an economic perspective, despite a higher initial fabrication cost of the PCD die, the total monthly operational expenses were reduced by approximately 20–25%, due to fewer replacements, lower downtime, and improved energy efficiency. The Return on Investment (ROI) analysis shows that the initial R&D cost can be recovered within less than 12 months, making the innovation both technically and financially sustainable.

From a managerial viewpoint, this study provides a blueprint for technology-driven transformation in traditional manufacturing industries. Managers and decision-makers in the automotive supply chain can leverage these findings to:

- Adopt advanced materials such as PCD not only for tool substitution but as a strategic element of process innovation.
- Institutionalize data-driven design through simulation-based engineering approaches, improving predictability and control over quality parameters.
- Reinvest cost savings from efficiency gains into R&D and workforce training to strengthen long-term technological competitiveness.

From an academic and theoretical perspective, this study contributes to bridging the research-practice gap in manufacturing engineering by illustrating how design innovation can emerge within developing industrial ecosystems. The project demonstrates that localized engineering design, supported by computational modeling and experimental validation, can rival imported technologies in both performance and precision.

Finally, the success of this initiative reaffirms the capability of Iranian industrial enterprises to move beyond imitation and toward genuine innovation. The PCD die project of Koobesh Kavir Semnan represents not merely a material substitution but a paradigm shift—toward sustainable, knowledge-based, and innovation-driven production systems that align with global standards of smart manufacturing and Industry 4.0.

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### REFERENCES

1. Del Rey JC, Guerrero-Vacas G, Ochoa-Rodríguez M, Rodríguez-Alabanda O. Effect of Die Design and Lubricant on ZnAl15% Wire Drawing: An Experimental Approach with Pressure/Hydrodynamic and Conventional Drawing Dies. *Lubricants*. 2025 Oct 30;13(11):481.
2. Del Rey JC, Guerrero-Vacas G, Comino F, Rodríguez-Alabanda O. Models for the design and optimization of the multi-stage wire drawing process of ZnAl15% wires for spray metallization. *Materials*. 2024 Oct 31;17(21):5307.
3. Byon SM, Lee SJ, Lee DW, Lee YH, Lee Y. Effect of coating material and lubricant on forming force and surface defects in wire drawing process. *Transactions of Nonferrous Metals Society of China*. 2011 Mar 1;21:s104-10.
4. Lantcev EA, Andreev PV, Nokhrin AV, Blagoveshchenskiy YV, Isaeva NV, Boldin MS, Murashov AA, Shcherbak GV, Smetanina KE, Chuvil'deev VN, Tabachkova NY. Combined effect of SiC and carbon on sintering kinetics, microstructure and mechanical properties of fine-grained binderless tungsten carbide: A case of the DC arc plasma chemical synthesis WC nanopowders. *International Journal of Refractory Metals and Hard Materials*. 2024 Aug 1;122:106721.
5. Spradling D. Reduction of Tungsten in Cemented Carbide Manufacturing Tooling. Millennitek LLC; 2024 Apr 19.
6. Doshi Y. Tungsten Carbide Market Size and YoY Growth Rate, 2025–2032. Coherent Market Insights. 2025. Available from: <https://www.coherentmarketinsights.com/industry-reports/tungsten-carbide-market>
7. Drawing Die Market size, share and insights 2025–2031, by regions | Valuates Reports. Valuates Reports. 2025. Available from: <https://reports.valuates.com/market-reports/QYRE-Auto-4A10039/global-drawing-die>
8. OG Analysis. Global Shaped wire drawing dies market Report Insights and Growth Outlook to 2034 - Strategic Trade Shifts, Ta . openPR.com. openPR; 2025. Available from: <https://www.openpr.com/news/4090931/global-shaped-wire-drawing-dies-market-report-insights> .
9. PCD Drawing Dies Dynamics and Forecasts: 2025-2033 Strategic Insights. Datainsightsmarket.com. 2025. Available from: <https://www.datainsightsmarket.com/reports/pcd-drawing-dies-671236#>
10. Research and Markets. Global Automotive Fasteners Strategic Analysis Report 2023–2030: Massive Engineering Interest in Lightweighting Catalyzes Fastener Material & Design Innovations. Prnewswire.com. Cision PR Newswire; 2024. Available from: <https://www.prnewswire.com/news-releases/global-automotive-fasteners-strategic-analysis-report-2023-2030-massive-engineering-interest-in-lightweighting-catalyzes-fastener-material--design-innovations-302029478.html> .
11. Bhatnagar S, Mullick S. A study on the influence of reinforcement particle size in laser cladding of TiC/Inconel 625 metal matrix composite. *Optics & Laser Technology*. 2023 Jun 1;161:109115.
12. Callister Jr WD, Rethwisch DG. *Materials science and engineering: an introduction*. John Wiley & sons; 2020 Jun 23.

13. Davis JR, editor. ASM specialty handbook: tool materials. ASM international: Almere, the Netherlands; 1995: 10–450.
14. Kroiß T, Engel U. Optimization of Tool and Process Design for the Cold Forging of Net-Shape Parts by Simulation. InProcess Machine Interactions: Prediction and Manipulation of Interactions between Manufacturing Processes and Machine Tool Structures 2013 (pp. 419-437). Berlin, Heidelberg: Springer Berlin Heidelberg.
15. Troitskiy OA, Stashenko VI. Electroplastic wire drawing: A promising method of production of lightweight wire and cable. Journal of Machinery Manufacture and Reliability. 2015 Dec;44(8):758-65.
16. Maizza G, Pero R, De Marco F, Ohmura T. Correlation between the indentation properties and microstructure of dissimilar capacitor discharge welded WC-Co/high-speed steel joints. Materials. 2020 Jun 11;13(11):2657.