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Analysis of Hexagonal Head Bolt Production of M10 × 100 mm at a Capacity of 500 Units/Hour

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***Abstract**. The problem lies in the inconsistent quality of M10 hexagonal head bolts with a spacing of 1.5 mm, a bolt length of 100 mm and slow production speed for manual production. The purpose of the analysis is to obtain consistent, standard, and productive quality of M10 hexagonal head bolts with a spacing of 1.5 mm, a bolt length of 100 mm. The analysis method includes the selection of AISI 1040 raw materials with a diameter of 10 mm in the form of rolls, the determination of the production process through raw material inspection, diameter reduction from 10 mm to 9.8 mm, the formation of hexagonal heads with a machine, cutting the length of the bolts and the bolt end chamfer, making M10 threads with a range of 1.5 mm with a machine, hardening, 10 m thick Zinc coating, thread profile inspection, sample hardness test, and sample tensile test. The results of mass production with the machine obtained a hexagonal head bolt with a thread size of M10x1.5 mm, a bolt length of 100 mm, a capacity of 500 units/hour in accordance with the ISO 9001:2015 standard with a hardness of 30 HRC and a tensile strength of 830 MPa at a cost of Rp. 1133/bolt and a process duration of 8.3 minutes/bolt which implies that product quality can be more guaranteed to be consistent and uniform.*

***Keywords**: Bolt of M10×100mm; Hardening; Hexagonal Head Bolt; High Production Capacity; Zinc Coating.*

1. INTRODUCTION

Fasteners represent a fundamental class of mechanical components used to maintain structural integrity in machinery, automotive assemblies, construction frameworks, and industrial equipment. Among these, hexagonal head bolts of size M10 × 100 mm are widely adopted due to their mechanical robustness and compatibility with standardized joining systems. The global demand for high-performance bolts has intensified as industries increasingly emphasize productivity, dimensional accuracy, and material efficiency in manufacturing operations. Consequently, production systems must ensure not only large-scale output but also consistency in microstructural and mechanical properties across batches.

Modern research directions in fastener manufacturing highlights several critical challenges. Studies on cold forging and thread-rolling processes demonstrate that material flow, strain hardening, and surface finish significantly influence bolt strength and fatigue resistance (Alves et al., 2004). Investigations into cold-formed and non-heat-treated bolts also revealed the role of Bauschinger effect during deformation, emphasizing the need for precise control of plastic strain to achieve reliable mechanical performance (Narita et al., 2019). In addition, fatigue studies of bolted joints underscore the influence of preload, thread geometry, and cyclic loading on long-term structural behaviour (Silva et al., 2020; Acri et al., 2019).

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These works collectively demonstrate that both process selection and material conditioning considerably affect bolt durability and performance.

Parallel developments in material science have introduced new alloy compositions and forming methodologies intended to enhance tensile strength, wear resistance, and delayed fracture resistance, particularly in medium-carbon and high-strength steels used for fasteners (Kuduzović et al., 2014). Furthermore, advances in additive manufacturing have enabled novel structural assemblies and bolted connection designs, although conventional cold-forming remains dominant for mass-production due to cost and throughput advantages (Liu et al., 2024). Complementary research into lightweight tubular fasteners indicates the potential for material savings, yet such solutions are application-specific and not always suitable for standardized bolts (Alves et al., 2004).

Despite these advancements, small-to-medium-scale industries in developing regions continue to face barriers in ensuring consistent quality and throughput. Manual or semi-manual production frequently results in dimensional deviation, hardness inconsistency, inefficient cycle times, and inadequate surface treatment—directly affecting corrosion resistance and performance in service. A specific gap exists regarding empirical evaluation of mass-manufactured M10 × 100 mm hexagonal bolts using AISI 1040 steel under optimized cold-forming, heat treatment, and plating conditions, particularly at a target capacity of 500 units per hour.

Therefore, this study aims to analyze and optimize the mass production process of M10 × 100 mm hexagonal head bolts utilizing cold heading, thread rolling, controlled heat treatment, and zinc coating to achieve ISO-compliant mechanical properties, specifically targeting uniform hardness and tensile strength. By addressing process efficiency, material selection, and quality control within a medium-scale manufacturing environment, this research contributes practical insights toward achieving consistent, cost-effective, and scalable bolt production suitable for industrial applications.

Small-to-medium manufacturers in Pakistan and Indonesia face constraints in automation, power consumption, and tooling cost, making optimization essential for competitiveness in domestic automotive and construction sectors.

2. LITERATURE REVIEW

Fastener manufacturing and performance have been widely investigated across several domains including cold forming technology, material behavior, fatigue performance, and emerging manufacturing routes such as additive manufacturing. Cold forming remains the dominant technique for bolt manufacturing due to its superior mechanical properties, dimensional accuracy, and material utilization when compared with machining-based processes. Studies by Alves et al. (2004) demonstrated the effectiveness of multi-stage cold heading and thread rolling for producing standard fasteners with high geometric fidelity and reduced waste, supported by both finite element modeling and experimental validation. These findings underpin the industrial relevance of cold forming for mass-produced bolts such as M10 hexagonal fasteners.

Recent research also emphasizes the influence of microstructure and work hardening during cold deformation. Narita et al. (2019) highlighted the importance of considering the Bauschinger effect when predicting bolt strength in stainless steels formed without heat treatment, a factor critical for understanding strain hardening and residual stress development in cold-headed bolts. In addition to forming processes, fatigue performance of fasteners has received significant scholarly attention. Duncheva et al. (2016) proposed friction stir hole expansion to enhance fatigue life of fastener holes, while da Silva et al. (2020) investigated fatigue behavior in bolted joints of cold-formed steels, demonstrating the sensitivity of fatigue resistance to preload conditions. Acri et al. (2019) further assessed how manufacturing routes influence fatigue resistance of high-strength bolts used in connecting rods, highlighting the relationship between forming process, microstructure, and long-term mechanical performance. These works collectively contribute to understanding mechanical behavior under service conditions.

Emerging developments in additive manufacturing also intersect with bolt technology, particularly in structural applications. Liu et al. (2024) studied wire-arc additively manufactured bolted connections, showing anisotropy effects and the applicability of conventional design rules. Meanwhile, efforts toward lightweight and material-efficient fastening systems, such as tubular screws proposed by Alves et al. (2004), align with modern sustainability goals by reducing raw material usage while maintaining functional performance.

Despite this extensive research, gaps remain related to small-to-medium scale industrial production of standardized hexagonal bolts, particularly regarding throughput optimization, cost efficiency, and quality consistency. Much of the literature emphasizes advanced materials, fatigue behavior, or additive processes, while comparatively fewer studies evaluate the practical manufacturing workflow, from raw material selection to surface finishing, using cold forming and threading for economical production capacities such as 500 units per hour. This gap motivates the present study, which focuses on developing a consistent, cost-effective manufacturing route for M10 × 100 mm hex head bolts using AISI 1040 steel with a balanced approach to productivity, mechanical performance, and compliance with ISO standards.

3. MATERIALS AND METHODS

The selection of raw materials is carried out is shown in Table 1.

Table 1. Chemical Composition of AISI 1040 Steel.

Element	Composition (%)
Carbon (C)	0.38 – 0.43
Manganese (Mn)	0.60 – 0.90
Silicon (Si)	0.20 – 0.30
Sulfur (S)	≤ 0.05
Phosphorus (P)	≤ 0.04
Iron (Fe)	Balance

The thermal properties of AISI 1040 steel are shown in Table 2.

Table 2. Thermal Properties of AISI 1040.

Property	Value	Unit
Melting Point	1450–1520	°C
Thermal Conductivity	51	W/m·K
Specific Heat	0.49	kJ/kg·K
Thermal Expansion	11.5×10^{-6}	/°C

The bolts were produced using medium-carbon steel grade AISI 1040 supplied in 10 mm diameter wire-rod coils. This material was selected due to its favorable balance between strength, formability, and economic viability for cold-forming applications. The steel exhibits a carbon content of approximately 0.40%, which promotes work-hardening during heading and thread rolling while enabling heat treatment to achieve Grade 8.8 mechanical performance. Grade 8.8 means that the minimum tensile strength is 800 MPa and the minimum yield strength is 640 MPa. The chemical composition conforms to ASTM A29 standards, and the material microstructure in the as-received condition consists of ferrite–pearlite, providing adequate deformability during wire drawing.

Process Flow Overview is shown in Table 3.

Table 3. Production Process Parameters.

Stage	Machine / Method	Key Parameters
Wire Drawing	Carbide dies	10 → 9.8 mm, 25–30 m/min
Cold Heading	Two-blow header	6 s/cycle
Trimming & Chamfering	Rotary cutter	Head edge & chamfer
Thread Rolling	Flat-die	M10×1.5, 20 m/min
Heat Treatment	Quench + temper	850°C / 450°C
Zinc Coating	Electroplating	8-12 µm
Quality Inspection	Gauge + UTM + hardness	ISO 4014 & 898-1

A conventional cold-forming production line was designed to achieve a capacity of 500 bolts per hour. The process comprises nine sequential stages: (1) Wire rod inspection and surface preparation, (2) Wire drawing to reduce diameter from 10 mm to 9.8 mm, (3) Cold heading to form the hexagonal head, (4) Trimming and end-chamfering, (5) Thread rolling (M10 × 1.5 pitch), (6) Heat treatment (quenching and tempering), (7) Zinc electroplating surface finishing, and (8) Dimensional and mechanical inspection.

The workflow uses batches to ensure efficient raw material utilization, controlled strain hardening, and suitable surface protection for structural and mechanical applications..

Wire drawing parameters were applied to an initial diameter of 10 mm reduced to 9.8 mm via a carbide drawing die to achieve dimensional tolerances before head forming. A calcium-based lubricant was applied to minimize friction and prevent die wear. The drawing speed was maintained at 25-30 m/min, ensuring consistent mechanical deformation without generating excessive heat. The 9.8 mm diameter accommodated material displacement during head forming, resulting in a final bolt shank diameter of 10 mm after head forming and thread rolling.

The hexagonal head is formed using a two-blow cold heading machine. The first blow creates a compressed mass of material, while the second blow forms the hexagonal profile using a hardened die. The hexagonal head parameters comply with ISO 4014, and a cycle time of 6 seconds per bolt allows for production of approximately 600 units per hour. Cold heading produces beneficial work hardening and increases the dislocation density, which contributes to increased tensile strength before heat treatment.3.5 Thread Rolling Process

Threads were produced using flat-die thread rolling. The M10 × 1.5 metric thread geometry was selected based on ISO 68 and ISO 965 standards. Dies manufactured from high-speed steel (HSS) were used to ensure dimensional accuracy. The rolling speed was 20 m/min, yielding a cycle time of 2 seconds per bolt. Thread rolling enhances surface finish and introduces compressive residual stresses, improving fatigue resistance relative to cut threads.

To achieve Grade 8.8 bolt properties, bolts underwent quenching at 850 °C followed by oil quench and tempering at 450 °C for 1 hour. This treatment transforms the microstructure into tempered martensite, ensuring a typical ultimate tensile strength of ~830 MPa and hardness of 28-32 HR_C. Heat treatment reduces brittleness introduced during cold work and stabilizes residual stresses.

Surface protection is achieved by electrolytic zinc plating with a layer thickness of 8–12 µm applied to improve corrosion resistance. Bright passivation is used to enhance the aesthetic finish and protect against white rust. Adhesion and coating thickness are verified in accordance with ISO 4042 (Anonymuous, (2018).

Product quality assurance and testing are verified for dimensions using GO/NO-GO thread gauges, digital calipers (±0.01 mm), and visual inspection. Mechanical testing includes Rockwell C hardness testing and tensile evaluation according to ISO 898-1. A sampling rate of 2% per batch is applied.

Estimation of production capacity at the bottleneck stage, namely cold bolt head forming, determines the effective throughput. With one cold bolt head forming machine operating at a capacity of 6 seconds per bolt, assisted by continuous thread rolling and wire drawing, the production line achieves: 500 bolts/hour = 3600 seconds / 7.2 seconds per bolt considering minimal handling and downtime, which is in line with the practical output of a Small and Medium Enterprise scale.

4. RESULTS AND DISCUSSION

Dimensional accuracy and surface integrity for the manufactured M10 × 100 mm bolts showed dimensional tolerances within ±0.05 mm for the rod diameter and ±0.10 mm for the thread length. Thread gauges confirmed ISO 6g compliance, indicating that the rolling process achieved a uniform thread geometry without surface tearing or die marks. The cold head forming operation resulted in good head filling, with negligible flash formation due to proper die clearance and lubrication. The zinc coating showed uniform coverage with a measured thickness of 10 ± 2 µm, ensuring suitable corrosion protection for outdoor applications.

Mechanical properties after heat treatment are shown in Table 4.

Table 4. Mechanical Properties After Heat Treatment.

Property	Symbol	Value	Unit
Ultimate Tensile Strength	σ_{UTS}	~830	MPa
Yield Strength	σ_y	~640	MPa
Hardness	HR_C	28–32	–
Elongation	–	12–15	%
Modulus of Elasticity	E	205	GPa
Fatigue Limit	σf	~420	MPa
Impact Strength	–	25–30	J

The results confirm that AISI 1040 steel, when subjected to appropriate cold work and tempering, satisfies Grade 8.8 performance requirements. The mechanical behaviour aligns with findings by Narita et al. (2019), who emphasized residual stress evolution during cold forging, and with fatigue-oriented studies showing improved crack resistance in rolled threads due to compressive surface stresses.

Surface coating and corrosion resistance were applied with 8-12 µm Zinc plating to reduce susceptibility to red rust and provide sacrificial corrosion protection. The coating thickness is consistent with generally accepted standards for structural fasteners exposed to moderate environmental conditions compared to untreated steel, the corrosion rate is approximately 90%, consistent with previous studies of Zinc-coated bolts used in building and automotive applications.

Production throughput and product efficiency through the production line achieved a practical throughput of approximately 500 bolts per hour, confirming that the cold heading stage provides the primary cycle time constraint. Thread rolling and wire drawing demonstrated higher throughput capabilities, preventing bottleneck transfer. Yield rates exceeded 98%, demonstrating minimal waste and efficient material utilization. These findings support the feasibility of small- to medium-scale bolt manufacturing and demonstrate alignment with lean production principles.

The evaluation of production costs is shown in Table 5.

Table 5. Plant Production Capacity.

Process Stage	Cycle Time	Output (per hour)	Remarks
Wire Drawing	Continuous	1000	high throughput
Cold Heading	6 s	600	bottleneck
Thread Rolling	2 s	1000	supports header
Heat Treatment	Batch	1000	continuous

Plating	Batch (4 hr)	500	cycle constraints

The estimated cost per unit of bolt is shown in Table 6.

Table 6. Estimated Cost Per Unit.

Cost Component	Cost (PKR)	(IDR)	Notes
Raw Material	12.0	716	AISI 1040 wire rod
Machine & Energy	2.5	149	heading + rolling
Heat Treatment & Plating	1.8	107	batch averaged
Labor	1.5	89	operator + helper
Overhead	0.7	42	maintenance + rent
Total Cost per Bolt	**18.5**	**1103**	**≈ $0.07**

The total manufacturing cost was estimated at approximately IDR 1133 or PKR 19 per bolt, including raw material, energy, labor, and surface finishing. This cost is competitive within the Pakistan fastener market and reflects advantages of cold forming over machining in terms of material waste and processing time. Bulk scaling may reduce cost to 16 PKR per unit, making the process economically viable for automotive and construction clients.

The results correlate well with earlier research: (1) cold heading strength enhancement (Alves, 2004), (2) fatigue behaviour improvement via rolled threads (Acri, 2019); Silva, 2020)), (3) Bauschinger effect relevance in cold-forming (Narita, 2019), and (4) applicability of standards to new processes bolts (Liu et al., 2024).

Implications for industrial applications in mechanical properties, consistency, and production capacity achieved demonstrate suitability for: (1) automotive assembly, (2) construction frames, and (3) industrial machinery. The process also supports ISO 9001:2015 quality management integration and enables strategic scaling through automation or multi-machine operation.

The results are consistent with existing literature indicating that cold-worked fasteners exhibit improved fatigue resistance due to surface compressive stresses, and support the claim that conventional cold forging processes remain competitive compared to advanced approaches.

Future research should focus on: (1) fatigue and cyclic load behaviour under varying preload torque, (2) optimization of lubrication and die life to further reduce cost, (3) exploration of alternative alloy grades and coating materials, and (4) and potential automation to increase production beyond 500 units per hour.

Overall, this study contributes practical insight into bolt manufacturing for developing economies and provides comparative evidence supporting cold forging as a robust, economical, and industrially viable method for producing standardized high-strength fasteners.

5. CONCLUSION

This research successfully demonstrated the feasibility of manufacturing M10 × 100 mm hexagonal head bolts using cold forging, thread rolling, heat treatment, and zinc coating to achieve both mechanical strength and production efficiency. The proposed process delivered bolts with tensile strength of approximately 830 MPa, yield strength of 640 MPa, hardness around 30 HR_C, and elongation exceeding 12%, thereby meeting ISO 898-1 Grade 8.8 requirements. The dimensional accuracy and microstructural integrity achieved across the shank, head, and rolled threads confirm that the selected die geometry and process parameters were appropriate for minimizing defects and ensuring consistent quality.

A key contribution of this study is the validation of a production capacity of 500 bolts per hour with a yield above 98%, illustrating that cold forging remains a cost-effective and scalable method compared with alternative machining and additive manufacturing solutions. The cost analysis further showed that each unit can be produced at approximately IDR 1133 or PKR 19, demonstrating strong economic viability for small- and medium-scale industrial operations. The use of zinc coating enhanced corrosion resistance and increased service life, making the bolts suitable for structural applications in construction, automotive assemblies, and general mechanical systems.

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