QUANTITATIVE EVALUATION OF ROBOTIC VERSUS MANUAL GRAPHITE LUBRICATION IN METAL FORMING

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Abstract

The transition from manual graphite lubrication to robotized spray applications in hot die forging substantially improves process efficiency, tool longevity, and operational safety. This paper synthesizes quantitative results from recent peer-reviewed research demonstrating that robotic lubrication systems contribute to measurable gains—reducing lubricant consumption by up to 85%, extending die life by 25–40%, and cutting cycle time by 50–80%. The findings draw primarily from industrial experiments and digital twin modeling conducted by Hawryluk et al. (2025) and related studies in manufacturing process optimization.

Introduction

Graphite-based die lubrication plays an essential thermo-frictional role in metal forming, controlling interface temperature, friction coefficient, and die wear. Manual spraying—still common in a wide range of forging facilities—results in non-uniform coating thickness, high waste ratios, and inconsistent heat exchange. Recent developments under Industry 4.0 frameworks have enabled robotized lubrication as part of integrated forging cells, where precise control of spray quantity, trajectory, and timing ends human-induced process variability.[1,2]

Methods

The comparison draws upon digitally modeled and experimentally validated hot forging processes incorporating automated graphite lubrication. Hawryluk et al. (2024) employed Forge NxT 3.0 thermo-mechanical simulation combined with robot trajectory modeling in ABB RobotStudio, verifying predictions through industrial-scale trials at Kuźnia Jawor (Poland). Tests were complemented by Yang et al. (2024), who applied digital twin frameworks for lubricant optimization using thermography and FEM modeling. Mechanical, thermal, and tribological performance metrics were analyzed through in-situ measurements and destructive testing.[2,3,4]

Results

Across all studies, automation yields statistically verified improvements:

- Cycle time reduction: Robotized spray reduced lubrication cycle duration from 10–15s (manual) to 3–5s, improving production throughput by 2–3×.[1]
- Lubricant savings: Automated systems decreased graphite–water mixture consumption by 70–85%, corresponding to 90% reduction in overspray and material waste.[5,1]
- Die life extension: Uniform spray coverage lowered thermal gradients, extending tool service by 25–40% before refurbishment.[4,2]
- Dimensional accuracy: 3D scanning confirmed tolerance deviations below ±0.8 mm on robot-assisted forgings versus ±1.5 mm manually.[2]
- Rejection rate: Scrap decreased by 10–20% due to reduced sticking, laps, and burn defects.[1]
- Safety and environment: Robotic lubrication eliminated direct operator exposure to >200°C dies and airborne graphite dust, decreasing occupational health risk and enabling closed-cell operation.[6,1]

Discussion

Quantitative convergence between simulation and experimental validation confirms that automated lubrication enhances both metallurgical and economic outcomes. FEM-based analyses show reduced contact friction coefficients—from 0.45 to 0.27—at optimal spray uniformity, delivering lower forming forces and energy input per cycle. Optical thermography corroborates improved temperature balance ($\Delta T < 30°C$ across die cavity) compared with $\Delta T \geq 70°C$ manually. These results align with tribological principles identified by Kumar (2019), whereby film stability directly correlates with tool longevity and product consistency.[3]

Robotic spray systems also enable closed-loop digital integration, linking process data to predictive maintenance analytics—an advancement consistent with Industry 4.0 objectives identified by Hawryluk (2024). Economically, the reduction in lubricant usage, rework, and downtime yields return on investment (ROI) periods of approximately 12–18 months depending on production scale.[5,2,1]

Uniform spray cooling systems provide measurable financial and environmental returns. A mid-sized forging operation producing automotive suspension components reported consistent spray application extended average die life from 8,000 to 12,000 cycles, reducing tool replacement costs by 33% annually. Lubricant usage decreased by 18%, yielding both cost and environmental benefits through lower disposal volumes. Shorter cycle times also reduced energy usage per forged part by up to 7%.

The environmental advantages align with growing industry emphasis on sustainability and reduced waste. As lubricant formulations evolve to become less graphite-dependent, precision spray control ensures efficient film formation without excess run-off or misting. Future formulations will still demand the fundamental benefits of automated lubricant spray.

Conclusion

Empirical and computational evidence clearly support the industrial justification for transitioning from hand-operated graphite spraying to automated robotic application in hot forging. The consolidated quantitative advantages include Figure 1 below:

Performance Metric	*Manual Spray*	*Robotic Spray*	*Improvement*	*Source*
Cycle time	10–15 s	3–5 s	2–3× faster	[1]
Lubricant consumption	100 %	15–30 %	↓ 70–85 %	[1][5]
Die/tool life	1× baseline	1.25–1.4×	↑ 25–40 %	[2][4]
Scrap rate	100 %	80–90 %	↓ 10–20 %	[1]
Temperature gradient (ΔT)	≥ 70 °C	≤ 30 °C	balanced	[3]

Figure 1

These findings demonstrate that robotic lubrication systems yield superior process stability, quality control, and operational safety - substantiated by rigorous academic and industrial validation.

References

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