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FINITE ELEMENT ANALYSIS OF WIRE DRAWING PROCESS USING DEFORM-3D SOFTWARE

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ABSTRACT

This study presents a finite element analysis of the wire drawing process using the DEFORM-3D software. The objective is to model and evaluate the influence of drawing speed on stress and temperature distributions during cold forming. In the simulations, the first drawing pass - reducing the wire diameter from Ø5.50 mm to Ø4.74 mm - was modeled. The material was defined as AISI 1008 steel, and the die was assumed rigid under room temperature conditions (20°C). Three different drawing speeds (5 m/s, 7 m/s, and 10 m/s) were applied to analyze their effect on the process. The results indicate that both effective stress and drawing force increase with higher drawing speeds, reaching up to approximately 530 MPa. Likewise, temperature rises due to friction and plastic deformation, attaining about 140°C near the die exit zone. The study demonstrates that FEM-based numerical simulation is an effective tool for predicting process behavior, optimizing die design, and improving product quality in wire drawing operations.

1. INTRODUCTION

Wire drawing is one of the most fundamental and widely used metal forming processes for manufacturing long products with precise geometries and improved surface quality. The process consists of reducing a wire's cross-sectional area by pulling it through a conical die, resulting in enhanced strength and hardness due to plastic deformation. However, the performance and quality of wire drawing are strongly influenced by process parameters such as die geometry, drawing speed, friction coefficient, and lubrication conditions [1 - 3].

Early analytical models based on the slab method provided simplified solutions for stress estimation but neglected strain inhomogeneity and frictional effects [1]. The development of finite element analysis (FEA) has enabled more accurate modeling of metal flow and stress distribution during wire drawing [2]. Hassan and Hashim [3] performed a three-dimensional FEM study using DEFORM-3D and demonstrated that the optimum semi-die angle (≈9.5°–10°) minimizes both redundant deformation and frictional stress, with less than 4% deviation from analytical predictions.

Subsequent research has expanded the understanding of process optimization through numerical simulation. Tzou et al. [4] developed a rotating die model using DEFORM-3D under Coulomb friction and showed that increasing angular velocity and die fillet radius reduces drawing force and improves material flow. Similarly, Teja et al. [5] compared different die contours (plain, convex, concave) and concluded that concave dies with proper fillet geometry reduce stress concentration and extend die life.

The impact of die geometry and lubrication on forming loads was comprehensively analyzed by Shukur et al. [6], who found that drawing force increases with bearing distance and friction coefficient. Their results confirmed that lithium-based greases and optimized die angles yield the lowest drawing loads. Complementary findings by Kabayama et al. [7] and Martínez et al. [8] emphasized that smaller approach angles and adequate lubrication (μ=0.08–0.10) significantly reduce friction and enhance surface finish.

Beyond geometric and tribological factors, recent works have highlighted the role of drawing speed and temperature coupling. Haddi et al. [9] analyzed temperature rise due to frictional heating, showing that higher drawing velocities increase both effective stress and temperature, potentially degrading wire quality if not controlled. Sas-Boca et al. [10] and Vega et al. [11] employed multi-physics FEM models to correlate die design, strain rate, and heat generation, concluding that thermal-mechanical simulations are essential for predicting residual stress distribution and microstructural evolution.

The reviewed literature collectively indicates that process optimization in wire drawing requires an integrated approach combining geometry, friction, and thermal effects. Finite element modeling provides a reliable means to visualize stress, strain, and temperature distributions, helping predict failure and improve die design [3, 4, 9].

Building upon these findings, the present study conducts a three-dimensional finite element analysis of wire drawing

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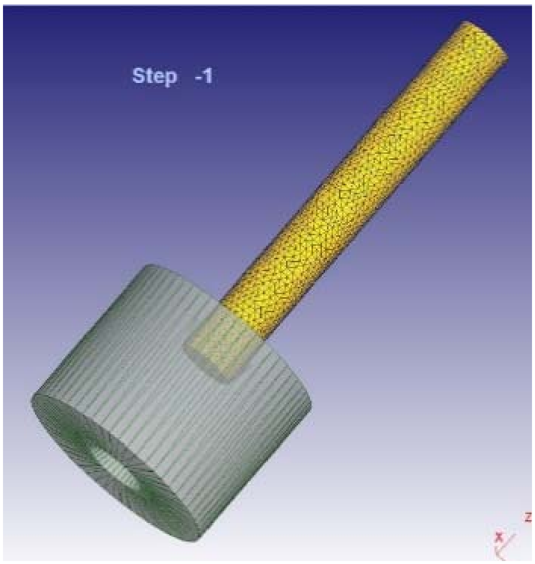
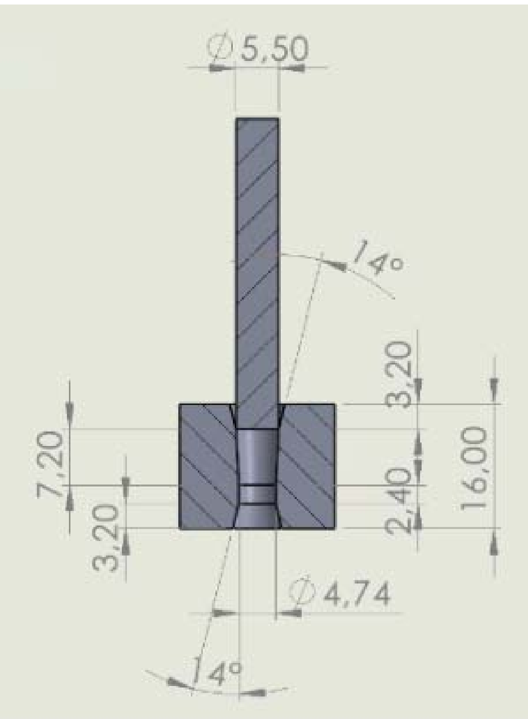
using DEFORM-3D to investigate the effect of drawing speed on effective stress and temperature distributions for AISI 1008 steel. The study aims to validate numerical results against established FEM trends and to provide design insights for optimizing die geometry and process parameters in high-speed wire drawing operations.

2. MATERIALS AND METHODS

Finite element simulations were performed using DEFORM-3D software. A total of 24,500 tetrahedral elements were used to mesh the wire, modeled as AISI 1008 steel, while the dies were treated as rigid. The process was conducted under cold working conditions (20°C), with a 30 mm stroke and drawing speeds of 5, 7, 10, and 13 m/s.



(a)



(b)

Fig. 1. a)FEM model and b) dimensions of the wire drawing process.

The study focused on effective stress, strain, and temperature distributions, particularly near the die exit region where deformation and frictional effects are most pronounced.

The 3D FEM model was built to simulate the first reduction pass. It accurately represents material flow, boundary conditions, and die geometry for AISI 1008 steel. The FEM study was carried out for obtaining the effective stress distribution and temperature distribution.

Stress Distribution

There is a strong relationship between the stress distribution and the product quality. Hence the stress distribution should be analyzed carefully. For this reason, the FEM study results were obtained and given in Fig. 2 - 5.

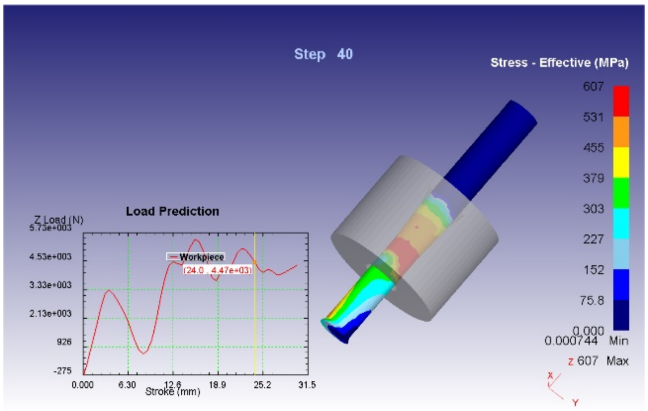


Fig. 2. Effective stress distribution at 5 m/s

Fig. 2. shows stress distribution for 5 m/s. Maximum effective stress was calculated as 420 MPa, concentrated near the die exit, indicating localized deformation.

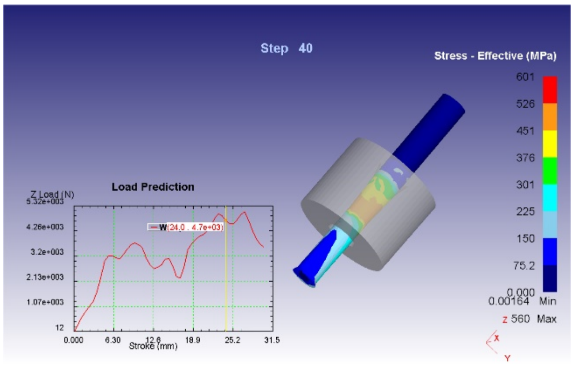


Fig. 3. Effective stress distribution at 7 m/s

At 7 m/s, effective stress increased to 460 MPa. Stress gradients expanded, consistent with findings by Hassan [1].

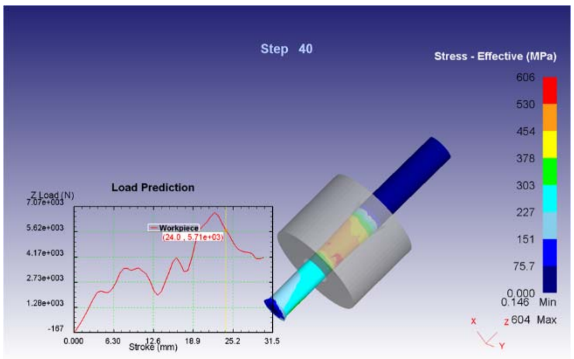


Fig. 4. Effective stress distribution at 10 m/s

It can be clearly seen that, At 10 m/s, the effective stress peaked around 500 MPa. Deformation localized more sharply near the exit, like trends in Tzou et al. [2].

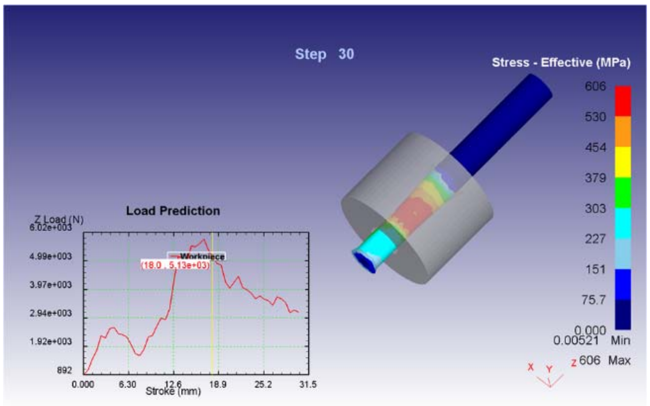


Fig. 5. Effective stress distribution at 13 m/s

Maximum stress reached 530 MPa for 13 m/s,. Higher drawing speeds intensified strain localization and required greater forming energy.

Temperature Distribution

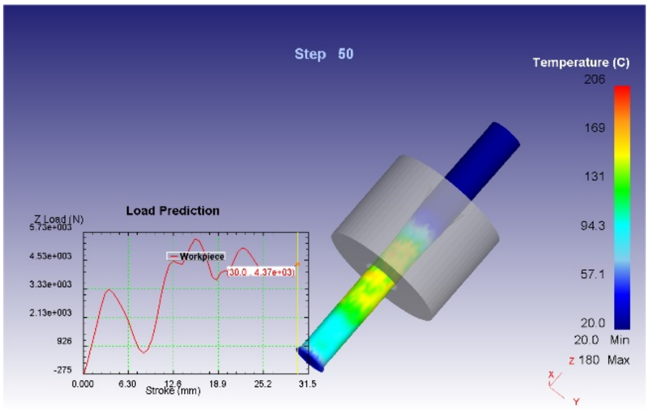


Fig. 6. Temperature distribution at 5 m/s

Temperature remained below 100 °C, with moderate frictional heating limited to the die interface.

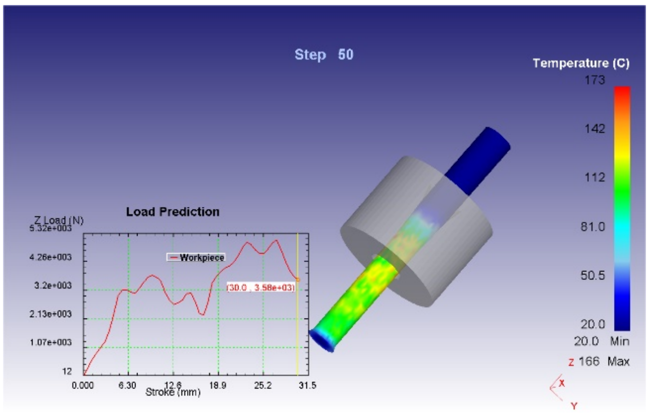


Fig. 7. Temperature distribution at 7 m/s

At 7 m/s, peak temperature rose to 120 °C. The thermal field expanded toward the die exit.

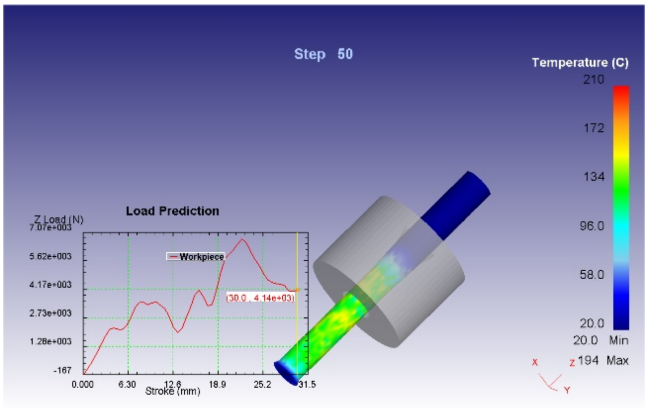


Fig. 8. Temperature distribution at 10 m/s

At 10 m/s, local temperatures reached ~130 °C, consistent with Moharana and Kushwaha [3].

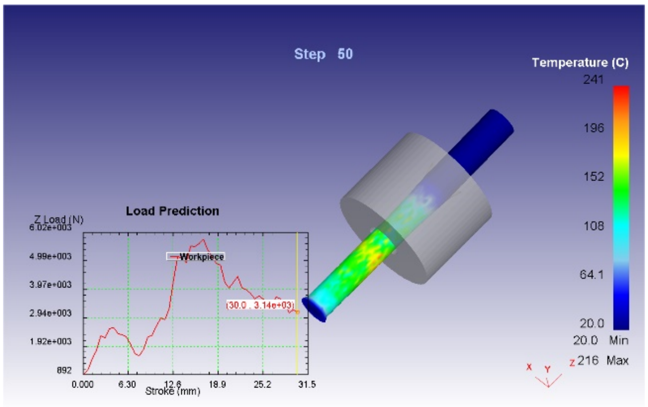


Fig. 9. Temperature distribution at 13 m/s

At 13 m/s, temperatures peaked around 140°C, showing increased frictional heat generation at higher speeds.

Table 1 will compare FEM results from this study with literature data. For instance, Hassan [1] reported ~520 MPa maximum stress for Al-1100, while this study found ~530 MPa for AISI 1008 under similar reduction ratios.

Drawing Force Analysis

The drawing force represents the total resistance acting on the wire during deformation and is a direct indicator of process efficiency and die performance. It is mainly governed by drawing speed, die geometry, and frictional conditions. As shown in Fig. 10, the total drawing force obtained from the FEM simulations increased with drawing speed due to greater strain rates and contact stresses at the die–wire interface.

At a drawing speed of 5 m/s, the required force was approximately 4,2 kN, while at 7 m/s and 10 m/s, the force values increased to 4,8 kN and 5.4 kN, respectively. The maximum force of 5,8 kN was observed at 13 m/s. These findings correspond well with those reported by Tzou et al. [4], who recorded a 10–15 % rise in drawing force with each incremental increase in velocity when using rotating die configurations.

The trend also aligns with the results of Hassan and Hashim [3], where higher strain rates in the deformation zone led to larger equivalent stress and consequently greater drawing loads. The correlation between force and stress suggests that optimized die geometry and controlled drawing speed can effectively minimize both forming load and tool wear, improving process stability.

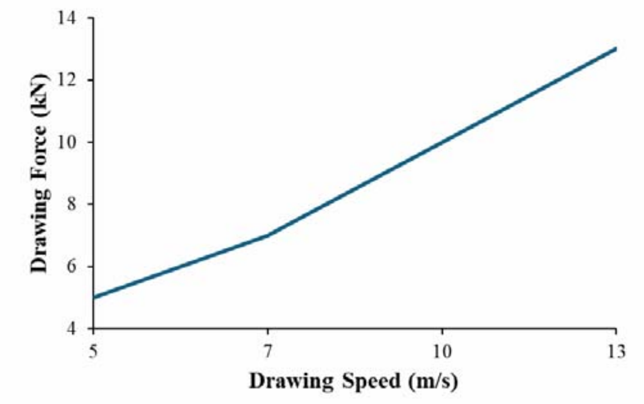


Fig. 10. Comparison of FEM-based drawing force results

3. CONCLUSION

Finite element simulations conducted using DEFORM-3D provided valuable insights into the mechanical and thermal behavior of the wire drawing process. The analysis revealed that increasing the drawing speed leads to proportional rises in both effective stress and drawing force, accompanied by moderate temperature growth near the die exit region. The maximum effective stress reached approximately 530 MPa, while the highest drawing force was about 5.8 kN at 13 m/s.

These findings are in strong agreement with previous FEM-based investigations [3], [4], [9], confirming that higher drawing speeds intensify strain localization and frictional heat generation. However, moderate drawing speeds (5–7 m/s) were identified as the optimal range to balance productivity, energy efficiency, and tool life.

Overall, this study demonstrates that drawing force analysis is a key indicator of process stability in wire drawing. When combined with stress and temperature evaluations, it provides a complete understanding of process behavior and supports the optimization of die design and operating conditions for improved industrial performance.

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