Simulation-based analysis of load and stress in 42CrMo4 gear blank and H13 die for improved forging performance

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Abstract. 42CrMo4 is a versatile alloy steel finds it's applications in forged automotive components. This paper investigates the effective load analysis of the 42CrMo4 alloy steel during forging. The final component is prepared via hot forging. Mechanical properties are evaluated using tensile testing machine and impact properties are evaluated using Impact testing machine. Hardness of the material is measured by using Rockwell Hardness tester. The microstructure is observed using Scanning Electron Microscope. The load prediction, effective strain, effective strain rate, effective stress was calculated by using deform software. The novelty of this paper presents the effective load the material 42CrMo4 can hold safely without failure or damage. Deform software simulations for 42CrMo4 steel identified safe limits of 6.52×10^7 N load, 4.46 strain, 2680 (mm/mm)/s strain rate, and 1810 MPa stress, ensuring reduced risk of failure.

1 Introduction

Many components are formed using forging process. Forging is a process of giving shape to the component by applying compressive forces through various dies and hammers. Forging has greatly advanced, moving from simple tools to sophisticated techniques like high energy rate forging. It provides notable advantages over other metal shaping methods, such as enhanced strength, toughness, reduced weight, and cost-effectiveness. The forging process has advanced from basic hammer and anvil methods to sophisticated, automated systems that utilize power hammers, robotics, and computer numerical controls [1,2]. Forging is a more efficient manufacturing process than methods like casting, as it creates higher quality products with less material waste [3].

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Hot forging is a versatile metal forming process used for various materials and complex geometries. Different materials exhibit distinct behaviours during hot forging. For steel components, hot forging at 1200°C is common in the automotive industry [4]. Stainless steels, such as AISI316 and AISI410, show improved slurry erosion resistance when hot forged at temperatures between 850°C and 950°C [5]. Al-Li alloys, important in aerospace applications, require careful consideration of temperature and strain-rate history during hot forging to achieve desired microstructures [6]. Forging process is employed for manufacturing connecting rods, crankshafts, gears, aerospace components etc due to its high strength, toughness and hardenability [7,8]. In the quenched and tempered condition, the material achieved a yield strength of up to 1188 MPa with an elongation of about 12%, as determined from tensile testing. These properties were obtained without any subsequent heat treatment, simply by forming the material after rapid cooling, making it suitable for use in gear blank applications [9,10].

Materials used for hot forging dies should exhibit high hardenability, excellent wear resistance, and strong resistance to both thermal and mechanical fatigue. Proper die design and material selection are crucial for die life and safety in hot forging operations [11]. Understanding the relationship between processing parameters and material behaviour is essential for optimizing hot forging processes across different materials and components. For hot working, din1.2344, H13 steel material is used for manufacturing forging dies. [12,13]. To improve the service life of forging dies, alternative hot-work tool steels such as QRO90 Supreme, W360, and Unimax were employed.

The microstructural evolution during hot forging—governed by factors such as temperature, deformation, and strain rate—significantly influences the mechanical behavior of the forged component [14]. In this article the safe load which can be applied is calculated for developing safe stresses as well the effective strain, effective stress rate developed on the material 42CrMo4 is calculated by using deform software. The study establishes a direct correlation between experimentally measured properties of 42CrMo4 steel and simulation-predicted safe limits, demonstrating that the material not only meets but validates industry standards for forging applications. This integrated approach of combining mechanical testing with Deform-based prediction offers a novel pathway to reliably assess forging performance and component durability.

2 Materials and methods

42CrMo4 alloy steel is used in hardened and tempered condition and can be further heat treated to enhance its mechanical properties. The heat treatment process involves heating to 820°C followed oil quenching and tempering further at 570 °C to get the desired mechanical properties.

Table 1. Elemental composition of H13 steel.

Element	**C%**	**Si%**	**V%**	**Mo%**	**S%**	**Cr%**	**Mn%**	**P%**	**Fe%**
Wt.%	0.4	1.1	1.1	1.4	0.0012	4.8	0.38	0.021	Bal.
Elemental composition of 42CrMo4									
Element	**C%**	**Si%**	**Mo %**	**P %**	**S%**	**Cr%**	**Si%**	**Mn%**	**Fe%**
Wt.%	0.4	0.22	0.2	0.001	0.002	1.1	0.3	0.8	Bal.

This alloy maintains a good balance between hardness, strength, and wear resistance, making it appropriate for high-stress situations. The job material used is 42CrMo4 and the material used for the forging die is H13 steel and the composition for the same is evaluated and is listed in Table 1.

2.1 Heat treatment layout

Heat treatment for the H13 die steel was carried out in Vacuum induction furnace. Hardening and three times tempering offers better combination of strength and toughness. H13 steel forging die
heat treatment is illustrated in Figure 1 a) and the heat treatment for 42CrMo4 is presented in Figure 1 b).

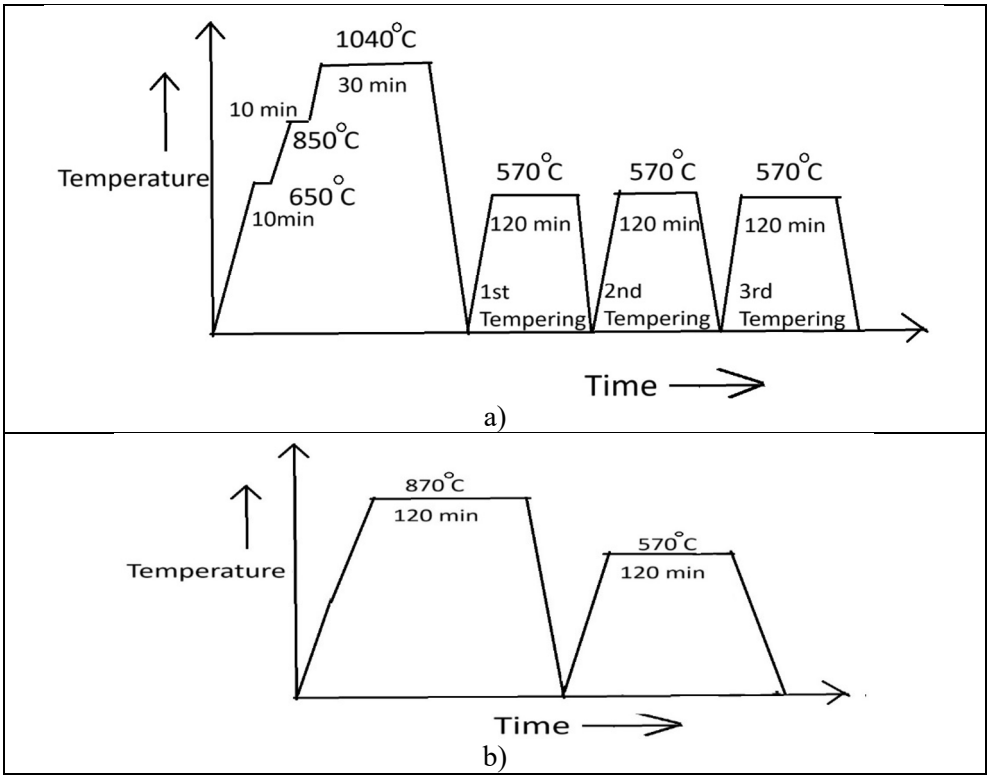


Fig. 1. Sequence of Heat treatment process for a) H13 die steel, and b) 42CrMo4.

2.2 Mechanical properties

The tensile characteristics were obtained by taking the average values from three specimens, each fabricated in accordance with ASTM A370 specifications, having a gauge length of 50 mm and a diameter of 12.5 mm. Hardness evaluation was carried out using a Rockwell hardness tester, taking multiple measurements at different locations on each specimen to ensure accuracy. The average hardness was determined by calculating the mean of three

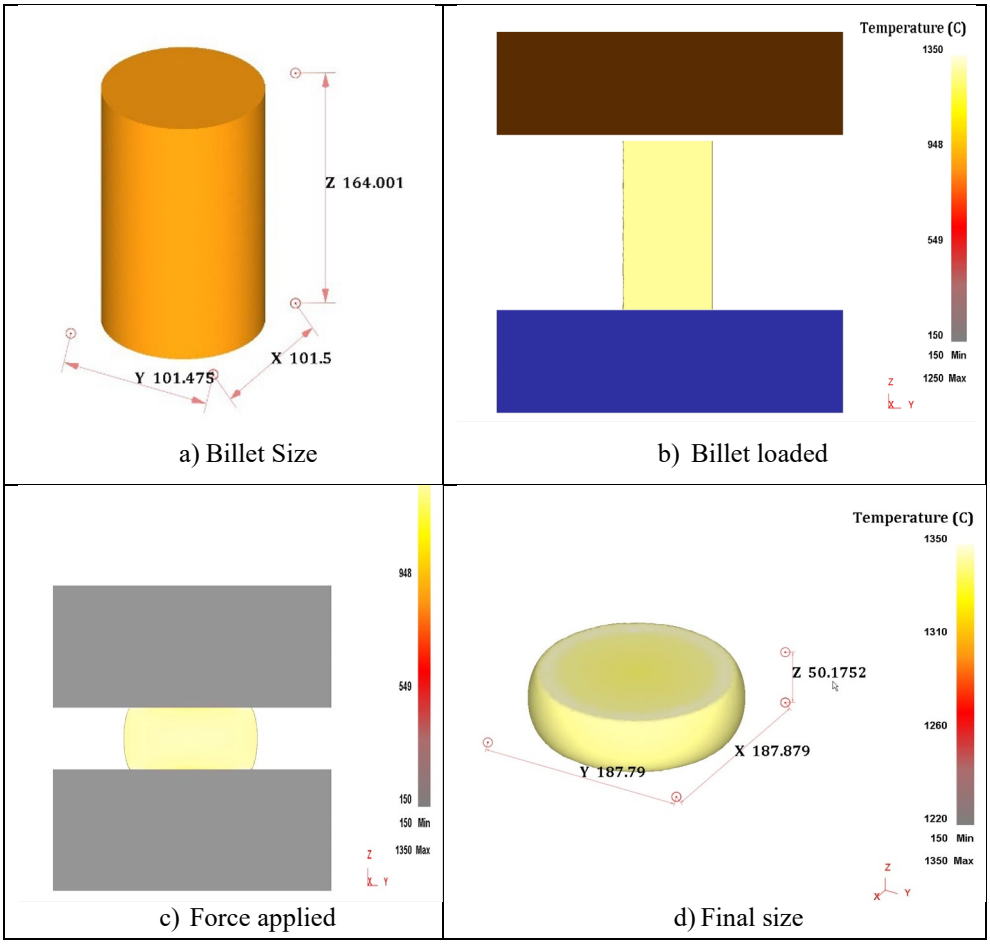
measurements. The specimens with dimensions of 10x10x55 mm were subjected to impact test and average values of 3 specimens were recorded.

2.3 Microstructure study

The tempered specimens were surface-finished using silicon carbide abrasive papers ranging from 600 to 7000 grit under a water stream, followed by polishing on a wool cloth with diamond paste. Subsequently, they were etched with a 4% nitric acid–ethanol solution to expose the microstructure, which was then analyzed through scanning electron microscopy (SEM).

2.4 Steps performed in software

The DEFORM simulations were performed under carefully set thermal and mechanical conditions to maintain consistency in results as illustrated by Figure 2.



a) Billet Size b) Billet loaded

c) Force applied d) Final size

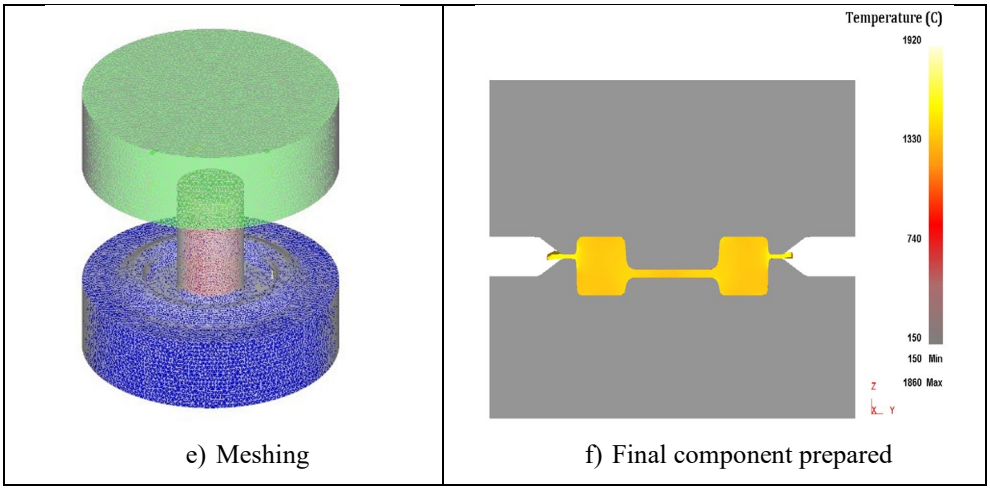


Fig. 2. Step by step process of simulation – a) Billet Size b) Billet loaded c) Force applied d) Final size e) Meshing, and f) Final component prepared.

A three-dimensional forging model was employed, where the mechanical and thermal characteristics of 42CrMo4, including elastic modulus and flow stress behaviour, were used as input data. The billet was considered deformable, whereas the H13 die was treated as rigid. A press load capacity of 2500 tons with die gap 3mm was specified to represent actual forging practice. Thermal boundary values were defined with a heat transfer coefficient of 11 N/sec/mm/°C at the die–workpiece interface and an emissivity of 0.8 to account for radiation. Contact conditions were described by a Coulomb friction model with a constant factor suitable for hot-working conditions. Tool velocity (300mm/sec), stroke length, and initial temperatures of billet 1250 ºC and dies were applied as boundary constraints to control material flow. Local mesh refinement was introduced in zones of high deformation to improve accuracy. The solver was executed in iterations until convergence was obtained, after which effective load, strain, strain rate, and stress distributions were extracted for evaluation.

3 Results and discussion

42CrMo4 and H13 steel was subjected to Heat treatment. It was evaluated that hardening and three times tempering offers better properties of H13 steel [13]. For 42CrMo4 austenitizing at 870 °C and tempering at 570 °C offers good combination of strength and toughness [14]. Tempering is done to relieve the internal stresses developed during quenching which avoids cracks formation.

3.1 Study of material behaviour

The uniaxial tensile load is applied on the specimens prepared from H13 die steel and 42CrMo4 material. The average values of the samples are presented in Table 2. The impact energy for 42CrMo4 was found to be 52 Joule showing it has improved potential to resist impact load. This property defines it suitability to use as the workpiece for the forging applications.

Table 2. Mechanical properties of material.

Sr. No.	Material	YS (MPa)	UTS (MPa)	% Elongation	Hardness (HRC)	Impact Energy (Joule)
1	H13 steel	1202	1405	15.8	48.2	15.58
2	42CrMo4	1001	1112	15.7	35.2	52

3.2 Morphology study

The microstructure for the hardened and three times tempered H13 steel is presented in Figure 3 a).

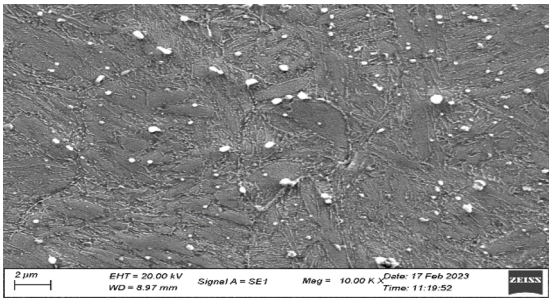
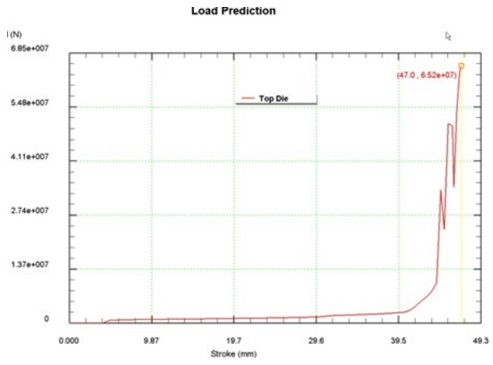


Fig. 3. Microstructure of H13 steel.

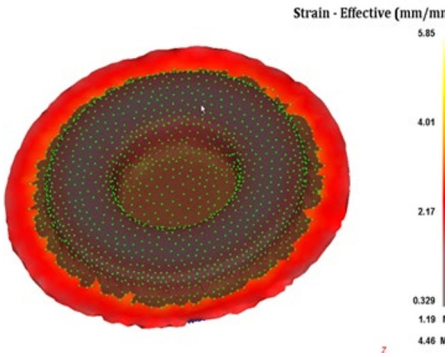
The H13 steel microstructure represents tempered martensite with transgranular carbides dispersed in matrix. The microstructure for the 42CrMo4 suggests fine carbide precipitations (like Fe3C) form during this process, which enhances ductility and impact resistance [15].

3.3 Deform 3D simulation

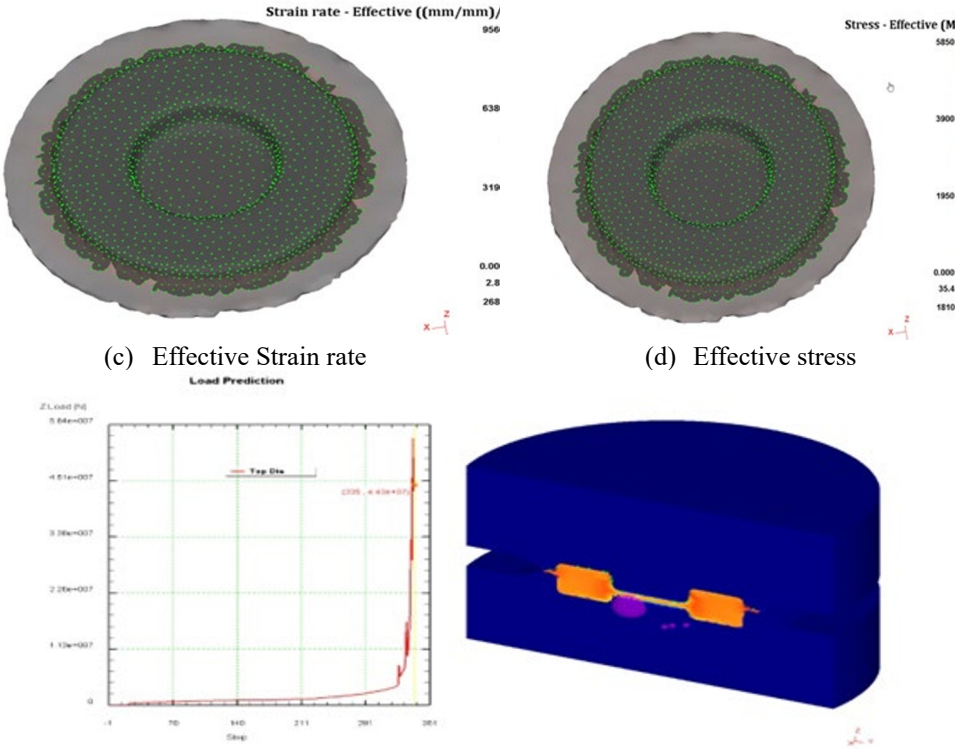
By using deform software the effective load, effective strain, effective strain rate, effective stress for material 42CrMo4 was evaluated and its performance under forging conditions was predicted.



(a) Effective Load



(b) Effective Strain



(c) Effective Strain rate (d) Effective stress

(e) Load prediction

Fig. 4. Effective load, effective strain, effective strain rate, effective stress.

This analysis allows for the optimization of the forging process, improvement of product quality, and better understanding of material behaviour. The fold step 326 was the simulation increment at which fold defect was detected. Deform can be used effectively to assess load and stress distribution illustrated in Figure 4. For the die prepared from H13 steel the von mises stresses developed was around 1321 MPa. The safe von mises stresses calculate for H13 die steel material using LS Dyna is found to be 1321MPa [7]. The tensile stress results obtained were aligned in the literature stated by Diefenbach et al. [10].

4 Conclusion

The mechanical properties for H13 die steel material after hardening and three times tempering found to be: UTS -1405MPa, YS-1202 MPa and Impact energy – 15.58 J.

The mechanical properties for 42CrMo4 after austenitizing and tempering found to be: UTS-1112MPa, YS-1001MPa and Impact Energy- 52 J.

The mechanical tests show that while H13 offers higher strength, 42CrMo4 provides superior toughness, making it more resistant to failure under forging loads. The safe limits predicted by Deform (load 6.52×10^7 N, strain 4.46, strain rate 2680 (mm/mm)/s, stress 1810 MPa) align with its measured properties and are consistent with literature and industry standards, confirming its suitability for reliable forging performance and extended component life.

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