THE ANNALS OF “DUNAREA DE JOS” UNIVERSITY OF GALATI
FASCICLE IX. METALLURGY AND MATERIALS SCIENCE
N°. 4 - 2025, ISSN 2668-4748; e-ISSN 2668-4756
Article DOI: https://doi.org/10.35219/mms.2025.4.02

SIMULATION REGARDING THE DAMASCUS STEEL BEHAVIOR ON MECHANICAL STRESS

Carmen-Penelopi PAPADATU, Dragos Bogdan OBREJA
Faculty of Engineering, “Dunarea de Jos” University of Galati, Romania
e-mail: cpapadatu@ugal.ro

ABSTRACT

The study of Damascus steel provided an opportunity to examine historical and specialized manufacturing techniques and to produce laboratory samples through the labour-intensive process of creating this material. It involves the free-forging of plates made from two types of high-carbon steel arranged in an interleaved structure, resulting in the "welding together" of these layers to produce a knife that is particularly resistant to stress and exhibits high hardness. The processing of the specimens and laboratory tests were carried out on Damascus steel samples produced in the laboratory, strictly following the procedure described in the specialized literature. The aim was to evaluate their mechanical properties and to process the results using Autodesk Inventor Professional 2023.

KEYWORDS: Damascus steel, treatment, mechanical properties, simulation

1. Introduction

In the production of Viking Age swords, various types of steel were used, often involving complex metallurgical techniques. Research papers specializing in the field provide insights into the types of steel and metallurgical practices that may have been relevant during that period. For example, the paper titled “Archaeo-metallurgical Investigation of a Fragment of a Medieval Sword Blade” [1] describes the use of different steel bars combined by hot hammering to achieve an optimal balance between mechanical properties such as hardness and impact resistance in the material. This technique involves wrapping a steel bar around a core of near-eutectoid steel (0.6-0.7% C) and applying a quenching heat treatment to increase its hardness.

Damascus steel was named after the capital of Syria. A version of Damascus steel was produced centuries ago in regions ranging from Indonesia to the Middle East. However, the formula for Damascus (Wootz) steel has been lost to history, as this type of steel was not developed until the 6th century [2, 3].

The first mentions of Damascus steel date back to around 300 BC (originally called "wootz") [2-4, 9, 10].

Studies on this type of steel can contribute to the development of new technologies and materials for the production of knives and other tools, making them far more durable [4, 5, 7, 8].

2. Materials and method

The material used for laboratory tests was laboratory-produced Damascus steel (consisting of 30 layers).

The investigated material comprises a hard steel with a carbon content higher than 0.9-1% C (AISI 1095) and a steel with a lower carbon content, but above 0.7%, respectively 0.75% C (15N20). These steels were processed simultaneously by hot free forging, resulting in a hard structure that displays "waves" with different shades of colour as a structural aspect (see Figure 2). This visually distinctive structure is characteristic of Damascus steel, known for its special mechanical characteristics (high hardness, good corrosion resistance, and particularly good behavior under shock loads) [3-6].

In the experimental process of preparing the samples (Damascus steel), the above-mentioned steels were used, producing a Damascus steel with 30 layers (as a package) formed by hot open forging.

The AISI 1095 and 15N20 steel plates had dimensions of 2 x 40 x 1000 mm. To remove the oxide layers and impurities, a belt grinding machine was used.

The semi-finished products were cut into 100 mm pieces and cleaned with a degreasing agent (as shown in Figure 1).

THE ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI
FASCICLE IX. METALLURGY AND MATERIALS SCIENCE
N°. 4 - 2025, ISSN 2668-4748; e-ISSN 2668-4756
Article DOI: https://doi.org/10.35219/mms.2025.4.02

***Fig. 1.** Laboratory samples, before the Forging process*

The process of obtaining Damascus steel involved - among other steps - the gradual heating of the system, first to 800 °C, then to 1100 °C - with the application of borax and forging under controlled conditions. After producing the Damascus steel, a knife blade with a pattern as shown in Figure 2 was obtained. Following the hardening treatment and tempering, the steel was tested in the laboratory to determine the evolution of its mechanical properties at different stress values, including processing of results using Autodesk Inventor Professional 2023.

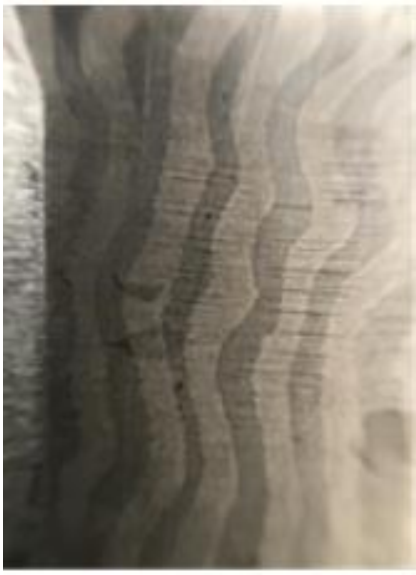

***Fig. 2.** The Damascus steel sample, from the laboratory*

3. Processing the results. Stress Analysis Report

A selection from a comprehensive finite element study of a Damascus steel knife blade conducted using Autodesk Inventor Professional 2023 is presented.

The objective of this study was to analyse the behavior of the blade under various loading conditions. The study includes the evaluation of Von Mises stress, strain and displacement to obtain information about the blade's response to applied loads.

If a load of F = 15 N is considered, the following results are obtained and presented below. In Table 1, the operating conditions are shown, corresponding to Force 1.

***Table 1.** Operating conditions*

Load Type	*Force value*
Magnitude	15.000 N
Vector X	0.000 N
Vector Y	15.000 N
Vector Z	0.000 N

The loads were applied to the selected face in Figure 3.

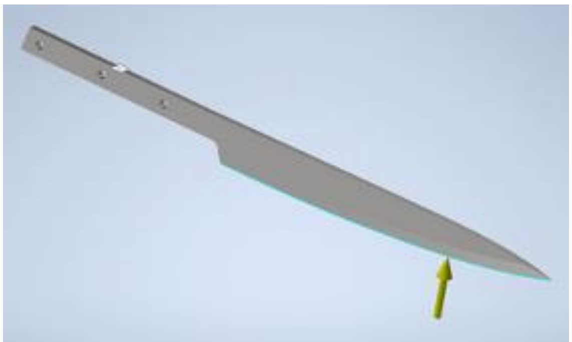

***Fig. 3.** Selected face of testing*

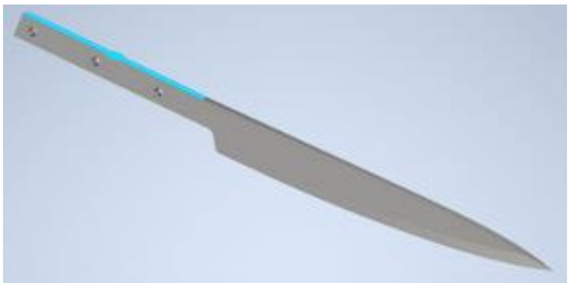

***Fig. 4.** Fixed Constraint-the knife handle, a rigid part*

Table 2. *Reaction Force and the Moment on Fixed Constraint*

Reaction Force		Reaction Moment	
Magnitude	Component (X, Y, Z)	Magnitude	Component (X, Y, Z)
15 N	0 N	2.604	-0.0300 Nm
	-15 N		0 Nm
	0 N		-2.6041 Nm

The Reaction Force and the Reaction Moment applied to the Fixed Constraint are presented in Table 2.

This displacement signifies minimal blade deformation under the given loads, highlighting its excellent rigidity and dimensional stability. The maximum X-Displacement value in this case (F = 15 N) is 0.00497 mm, and the minimum value is IS -0.00365 mm.

In Figures 5 and 6, Von Misses Stress and 1st Principal Stress are presented.

In Figure 5, within the shear zone, the maximum von Mises stress reaches 34.98 MPa. In Figure 6, for the 1st Principal Stress, the maximum value observed in the sample/knife is 20.93 MPa.

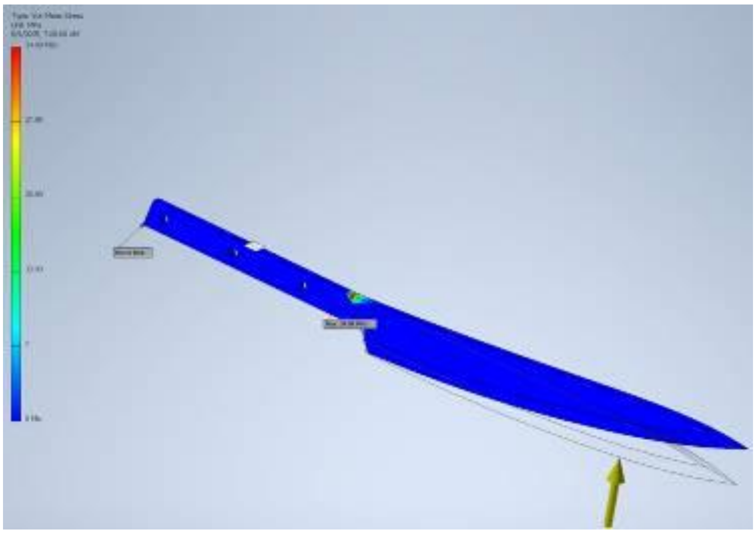

Fig. 5. *Von Mises Stress evolution*

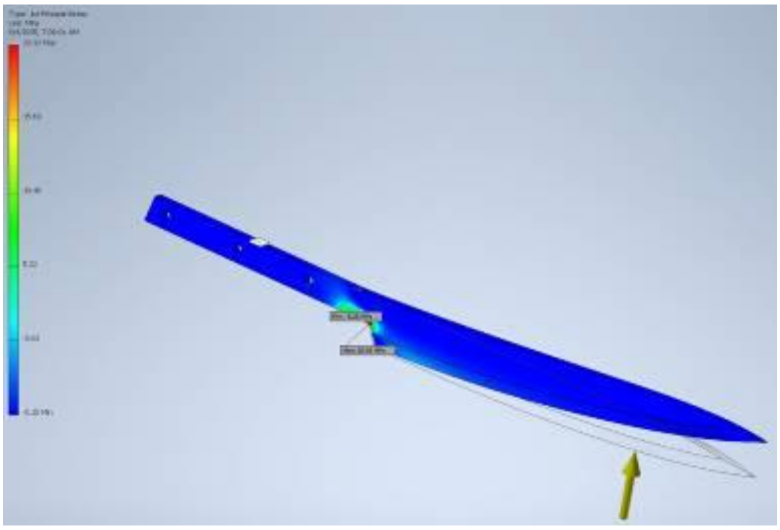

Fig. 6. *1st Principal Stress*

N°. 4 - 2025, ISSN 2668-4748; e-ISSN 2668-4756
Article DOI: https://doi.org/10.35219/mms.2025.4.02

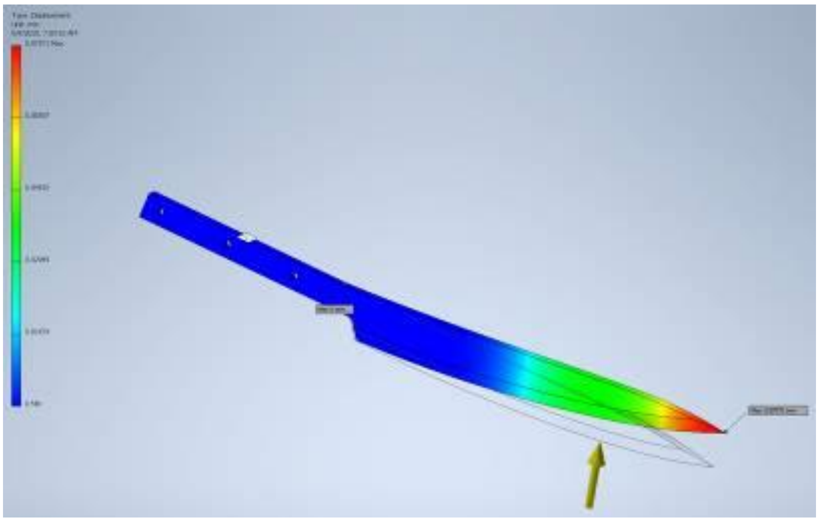

Fig. 7. *The Displacement of the sample during the load evolution*

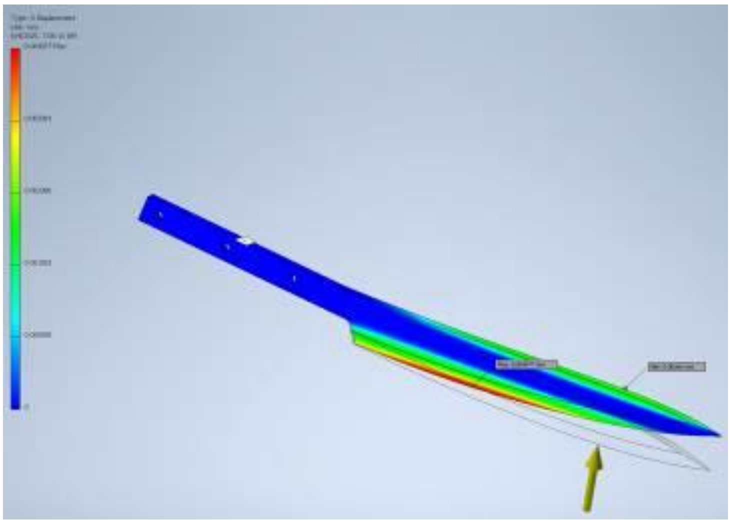

Fig. 8. *X-Displacement*

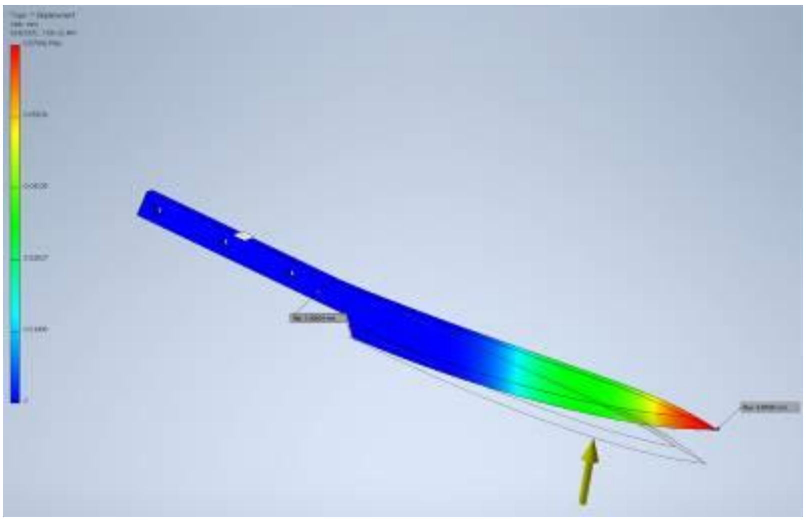

Fig. 9. *Y-Displacement*

Considering the displacement recorded during loading of the knife blade/sample, it can be stated that the maximum value reaches 0.07371 mm, which is imperceptible to the naked eye.

Considering that a small "displacement" of the blade occurs during loading, we can conclude that the material in question exhibits very low elasticity. No plastic deformations were observed during this loading.

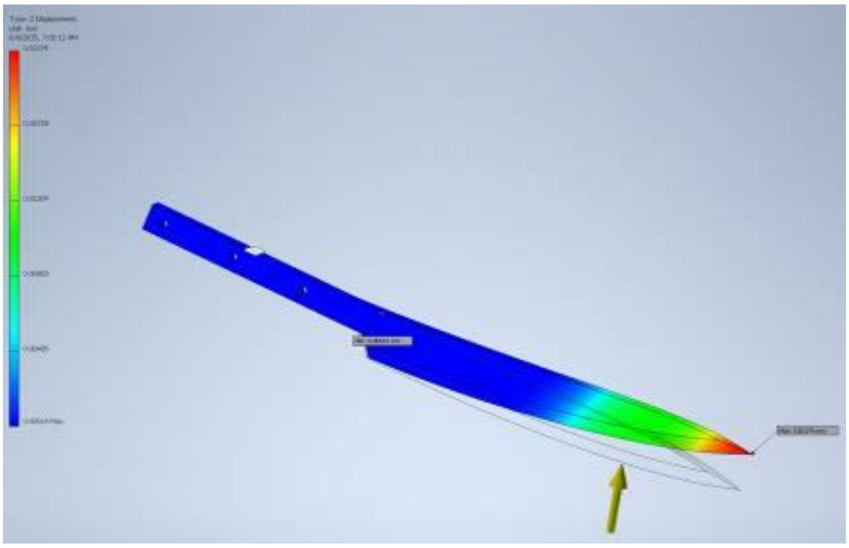

Fig. 10. *Z-Displacement*

Detailing the displacements along the three coordinate axes OX, OY, and OZ, the following maximum values are observed: 0.004977 mm for X-Displacement (see Figure 8), 0.07042 mm for Y-Displacement (see Figure 9), and 0.02174 mm for Z-Displacement (see Figure 10).

The displacements are very small, and the knife blade used as a laboratory sample does not undergo plastic deformation at this load.

4. Conclusions

A Damascus steel sample was produced in the laboratory, after studying the relevant literature, knowing that the original recipe was lost at the end of the 16th century. However, old works were found that formed the basis of the research. The first attempts to make Damascus steel in modern times were reported at the beginning of the 20th century. In the present study, two hypereutectoid steels with high carbon content and favourable mechanical properties were considered.

By intercalating plates of different steels and applying hot forging, a Damascus steel with good resistance properties was obtained.

The steel made in the laboratory exhibited exceptional behaviour under different stress values.

Additional studies, such as finite element analysis and strength-of-materials tests, were performed to understand and evaluate the behavior of Damascus steel under different scenarios and loading scenarios.

References

[1]. Merico P., *et al.*, *Archaeo-metallurgical Investigation of a Fragment of a Medieval Sword Blade*, Metallography, Microstructure, and Analysis, vol. 13, p. 257-271, https://doi.org/10.1007/s13632-024-01064-3, 2024.

[2]. Verhoeven J. D., *The mystery of Damascus blades*, Scientific American, 284, Article Number: 74, 2001.

[3]. Papadatu C. P., *et al.*, *Cercetarea comportării otelului de Damasc la solicitări statice*, Euroinvent 2025, Workshop proceeding, p. 221-230, Iasi, Romania, 2025.

[4]. Papadatu C. P., *et al.*, *Learning from the past: The reconstruction of the original Damascus Steel. Experimental Study*, International Journal of Conservation Science, ISSN: 2067-533X, DOI: 10.36868/IJCS.2023.03.07, 14, 3, p. 871-886, 2023.

[5]. Papadatu C.P., *et al.*, *Research on Testing a Genuine Damascus Steel. A Case Study*, International Journal of Conservation Science, ISSN: 2067-533X, DOI: 10.36868/IJCS.2023.04.07, 14, 4, p. 1367-1380, 2023.

[6]. Papadatu C. P., *et al.*, *Graphic Modelling and Equipment used in the Reconstruction of the Original Damascus Steel*, International Journal of Conservation Science, 15 (2), p. 979-992, DOI: 10.36868/IJCS.2024.02.15, 2024.

[7]. Belaiew N. T., *Le damas occidental et les lames damassées*, Métaux et civilisations, I, I, p. 10-16, 1945.

[8]. Verhoeven J. D., *The mystery of Damascus blades*, Scientific American, 284, Article Number: 74, 2001.

[9]. Panseri C., *Damascus steel in legend and in reality*, rev. Gladius, Nb. IV, p. 5-66, 1965.

[10]. Smith C. S., *A History of Metallography*, The MIT Press, Cambridge, Mass., 1988.