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Research Article

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The Influence of Detonation Velocity on the Microstructure of Materials in Free Explosive Forming

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Abstract

This paper investigates the influence of detonation velocity on the microstructure of materials subjected to free explosive forming. Explosive forming, a high-speed metalworking technique that utilizes shock waves from controlled detonations, enables the formation of complex geometries without the need for expensive tooling or presses. The study focuses on forming spherical components without the use of molds, utilizing segmented designs and various energy transfer media, including water. A physical model of a segmented sphere was created using 3D printing, followed by explosive forming using Poladyn 31ECO plastic explosive. Experimental work involved the fabrication of a six-segment steel sphere, formed and analyzed for microstructural changes using metallographic techniques. Metallographic analysis was conducted on the samples to assess changes in the microstructure. Results indicate that, under the tested conditions with relatively low explosive quantities, only minimal microstructural changes were observed, primarily a ferrite matrix with coagulated pearlite. The findings suggest that higher explosive charges are necessary to induce significant plastic deformation and observable microstructural transformations.

Article history

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Keywords

Explosive Forming, Detonation Velocity, Microstructure.

1 Introduction

Explosive forming represents a revolutionary approach to metalworking, utilizing controlled detonations to achieve plastic deformation at speeds exceeding 9.000 m/s. [1]. Unlike conventional methods that rely on hydraulic or mechanical presses, this technology utilizes shock waves generated by explosives to shape metal blanks into complex, large-scale workpieces, even several meters in size [2]. The first uses of this technology date back to 1888, when Charles Monroe used black powder to shape metal plates [3]. However, the technology truly advanced in the mid-20th century with applications in the aerospace industry for forming large components from titanium and aluminum [4]. By the late 19th and early 20th centuries, the first patents were filed, mainly driven by the needs of the aviation and space industries. In the 1960s, approximately 80 different projects were developed in parallel, resulting in the commercial application of explosive forming [4]. Companies specializing in this method were established, working with NASA to produce two-thirds of the Apollo spacecraft structure and developing 10-meter aluminum domes from Al 2014 alloy [5].

Due to its ability to process various materials and economic feasibility (eliminating the need for expensive tools or presses), explosive forming hasound applications in the automotive industry, architecture, and other sectors [6]. Studies show its wide use in metal processing [3], especially with underwater detonations, which produce nearly uniform shock waves suitable for forming aerospace materials without fracturing [1]. Most scientific papers on this subject were published between 1955

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and 1970, with a peak in 1970. Interest later declined, partly due to the emergence of technologies such as explosive welding, hydroforming, and superplastic forming, which were easier to integrate into existing workshops. Explosive forming requires specialized test sites [4], [7].

Explosively formed parts can reach or surpass conventional manufacturing tolerances [8]. With proper explosive charge type, shape, and quantity, tolerances of ±0.025 mm have been achieved on small parts. According to the authors [9], Domes 1000-1500 mm in size, with wall thicknesses of 2.3-3.8 mm, can achieve tolerances of 0.128 mm in diameter and 0.050 mm in thickness, which is better than the standard tolerances of 0.254 mm and 0.100 mm, respectively. For deep drawing of parts up to 500 mm, tolerances of 0.03 to 0.2 mm are possible [10].

2 Free Explosive Forming

Free forming is based on the relative displacement of material points due to the pressure of the shock wave.

Figure 1 illustrates the so-called free forming process, which is typically employed for workpieces where high dimensional accuracy is not required. With this method, the final shape of the product is determined by the size and distance of the explosive charge from the workpiece. The open die serves to ensure the formation of the edge contours of the piece. Sheet holders are used to prevent wrinkles or creases in the material. This method is used to form elliptical, spherical, and hyperbolic parts; however, care must be taken when handling the workpieces, as they exit the die at high speed and may become deformed upon impact.

Figure 2 shows free forming with a contact method [11], [12]. The explosive charge is placed along the entire length of the workpiece, with variations in the mass of the explosive used to achieve the specific energy required for the desired deformation. When forming a homogeneous workpiece with uniform wall thickness, the final shape will be determined by the amount of explosive charge, the detonation velocity of the explosive, the shape of the explosive, the placement of the explosive, and the medium used [13].

It is also possible to perform explosive free forming of spheres without a mold. The first step in this process involves designing the segments or geometry of the sphere to be formed. According to research, the sphere can be formed from three to six segments, with configurations using a greater number of segments proving to be the most effective. Such a configuration allows for a more even distribution of stress, particularly around the welded areas. Once the segments are welded into a single unit, the next step is selecting a suitable medium for energy transmission. The most commonly used media are air, water, and sand; however, other substances may also be employed.

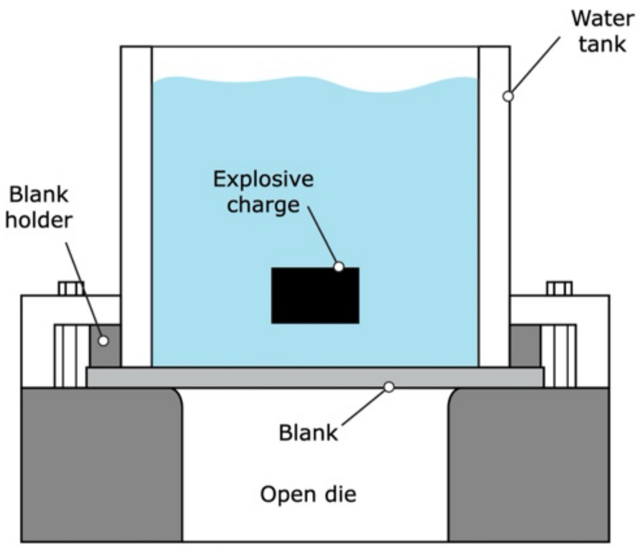

Figure 1 Non-contact free forming

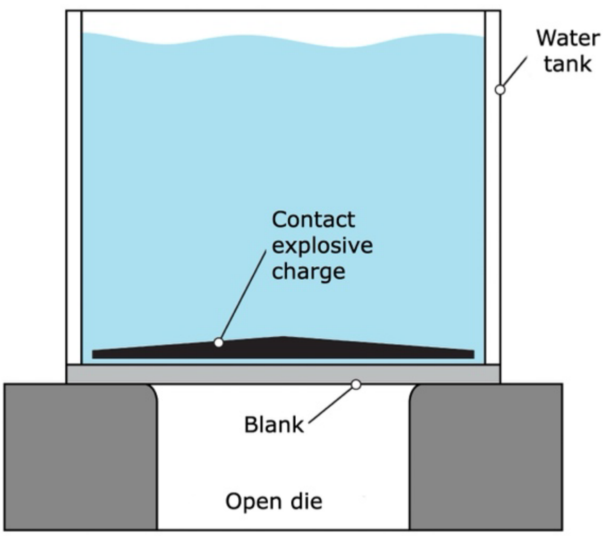

Figure 2 Contact free forming

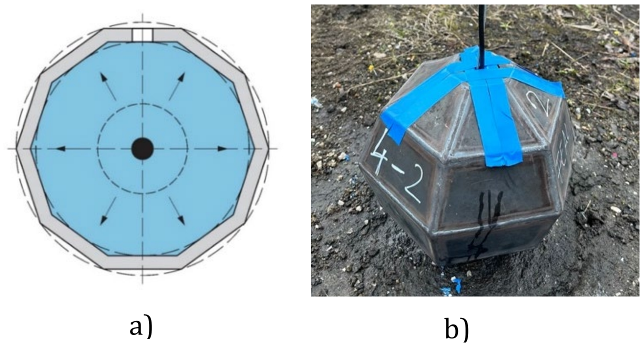

Figure 3 Free forming scheme and experiment

Before filling, an opening must be left at the top of the sphere to allow for the introduction of the medium as well as precise placement and centering of the explosive [14].

When water is used, the pressure of the shock wave spreads evenly through the medium, acting first on the points closest to the center of the explosion. As the distance from this center increases, the pressure intensity decreases, resulting in the plastic deformation of the flat segments into a curved spherical shape–provided that the appropriate forming parameters have been selected in advance. Figure 3a shows a schematic of the process of explosive sphere formation, while Figure 3b shows the experimental setup.

3 Experimental Work

At the Faculty of Mechanical Engineering, Computing and Electrical Engineering of the University of Mostar, a physical 3D model of the sphere was produced using a Zortrax printer and PLA material. Due to the dimensional limitations of the device, the sphere was printed in two separate parts. Before that, a 3D model of the sphere was created using the SolidWorks software, in which two versions were designed–one with six segments and one with eight segments. Based on the size of the sphere and the practicality of fabrication, the six-segment version was chosen, as it allows for larger segments and reduces the welding process. The diameter of the sphere was 205 mm, and its volume was 5 liters. The final model was imported into the Z-SUITE software for 3D printing preparation.

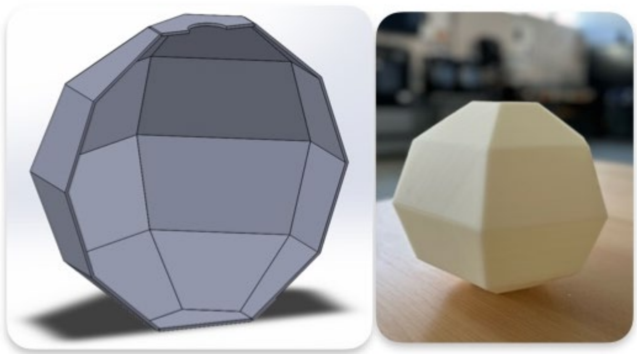

Figure 4 3D model i 3D print of the sphere

Figure 4 shows the SolidWorks model of the sphere and the fabricated 3D part.

Before the welding process began, a chemical composition analysis of the material was conducted at the Faculty of Mechanical Engineering, University of Džemal Bijedić in Mostar, and the results are shown in Table 1.

For the purposes of the experiment, the energy source used was the plastic explosive Poladyn 31ECO, which is suitable for use in both dry and wet conditions, and within a temperature range of -20 °C to 50 °C. The detonation of the explosive was initiated using a slow-burning fuse. It is essential to note that, even with properly defined forming parameters, the required amount of explosive can vary by up to 500% [15]. After determining the optimal parameters for the experiment, a specimen with a thickness of 1.5 mm was formed.

Water was used as the energy transmission medium, while the explosion was initiated utilizing a detonator containing 1 g of PETN, with a detonation velocity of 6000 m/s. Samples were submitted to the Kemal Kapetanović Institute in Zenica for metallographic analysis to examine the microstructure. Figure 5 shows the device used for microstructure testing. The sample labels represent the material thickness, the inner side of the sphere affected by the shock wave pressure, and the amount of explosive that acted on the sphere.

Table 1 Chemical composition of the material St12

Fe	C	Mn	Si	Al	Cu
99.581	0.078	0.168	0.010	0.043	0.029

Figure 5 Metallofraphic analysis

Table 2 shows the settings for metallographic analysis of samples 1, 4U, and 5U. All three samples exhibit a microstructure composed of ferrite and coagulated pearlite.

Table 2 Markings for material testing

Markings	
1	1.5 mm – undeformed
4U	1.5 mm – annealed
5U	1.5 mm – annealed, successfully deformed with an initial capsule of 1 g PETN

4 Results

A detailed metallographic analysis of samples 1, 4U, and 5U revealed a microstructure consisting of ferrite with coagulated pearlite (Figures 6-14).

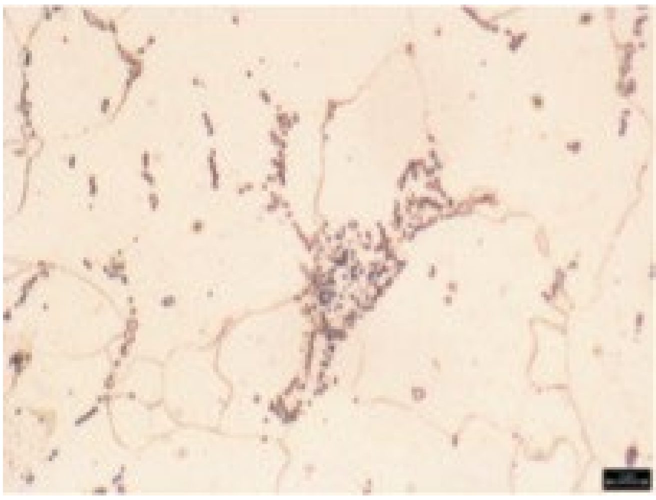

Figure 7 Sample 1 - microstructure x1000 detail

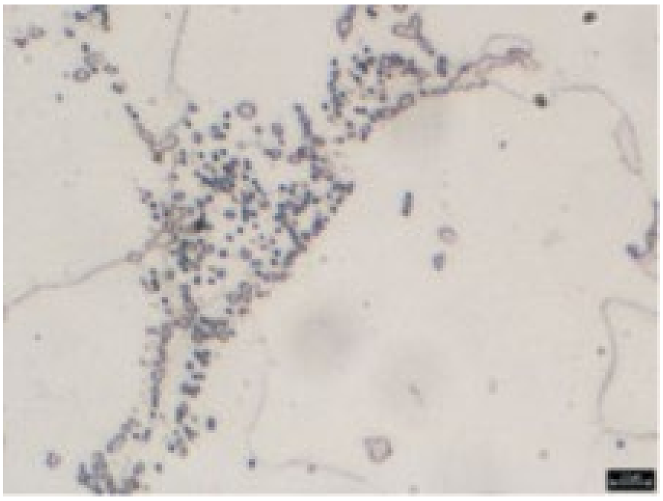

Figure 8 Sample 1 - microstructure x2000 detail

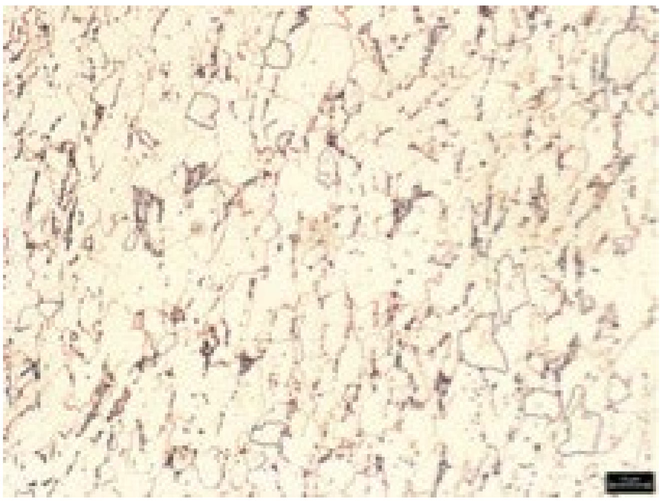

Figure 6 Sample 1 - microstructure x200

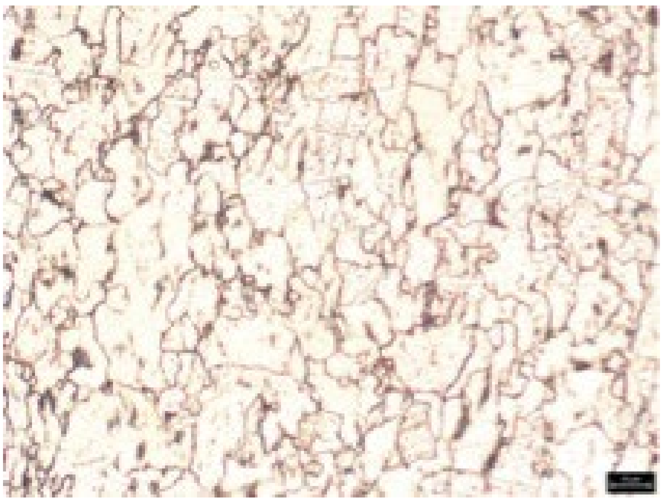

Figure 9 Sample 4U - microstructure x200

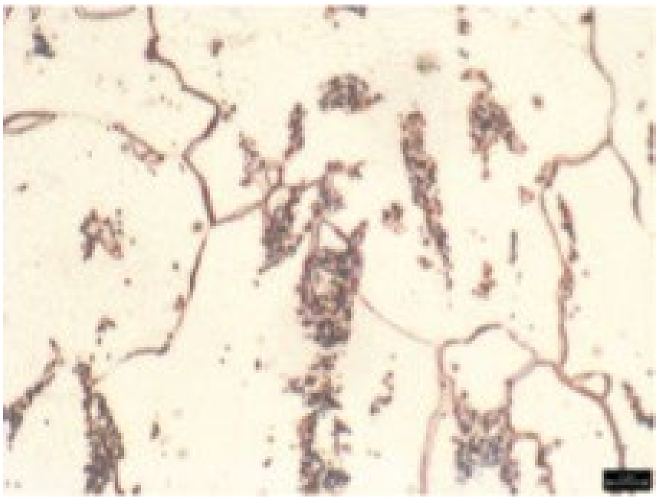
Figure 10 Sample 4U – microstructure x1000 detail

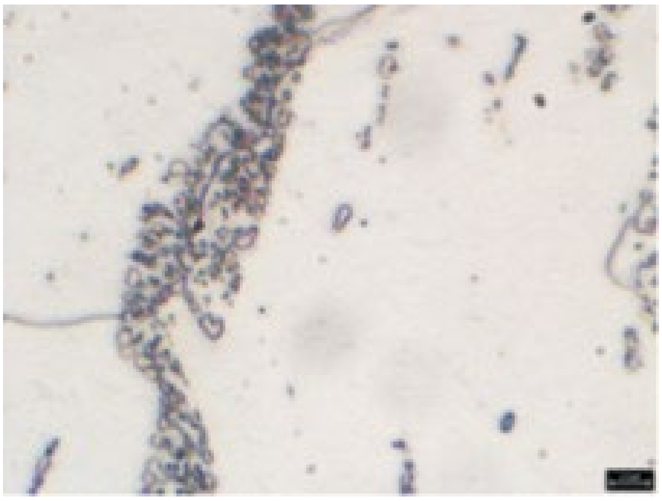
Figure 11 Sample 4U – microstructure x2000 detail

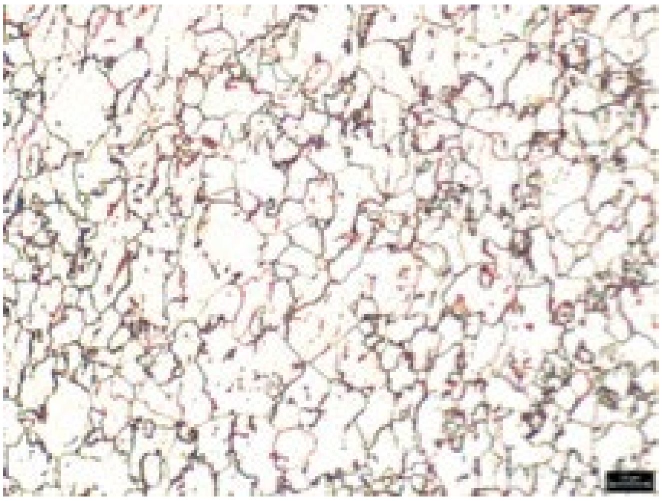
Figure 12 Sample 5U – microstructure x200

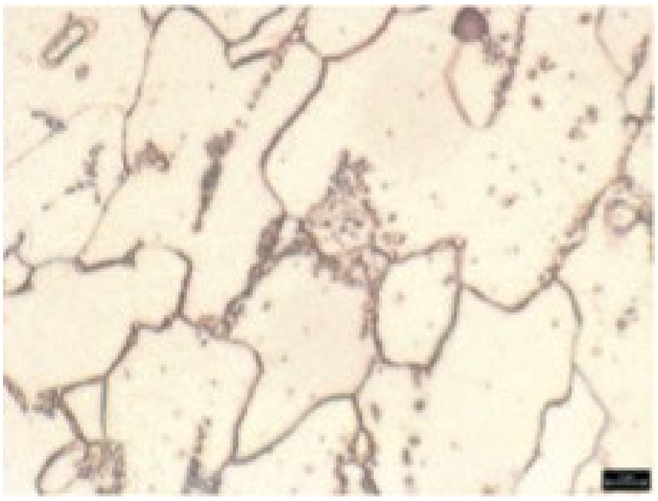
Figure 13 Sample 5U – microstructure x1000 detail

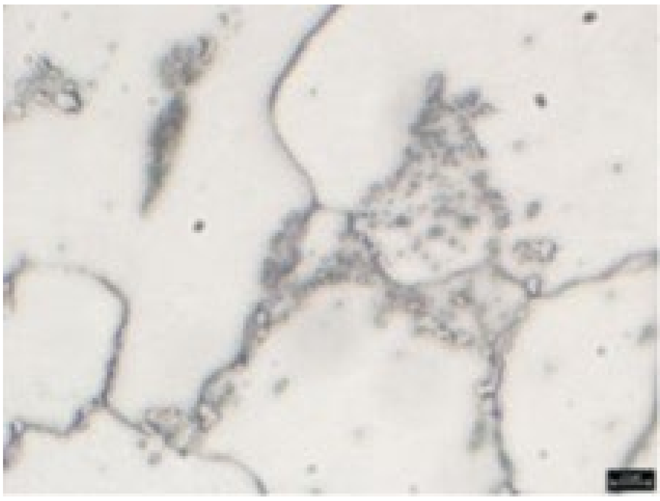
Figure 14 Sample 5U – microstructure x2000 detail

Due to the use of a relatively small amount of explosive in the conducted experiments, the metal underwent limited deformation, which made detailed microstructural analysis difficult. Metallographic examinations revealed minimal changes in the material structure, which were insufficient to draw conclusions about the effects of explosive forming in this case. By increasing the amount of explosive, more pronounced plastic deformations can be achieved, allowing for more precise observation of changes in the microstructure. This would ensure more relevant results for analyzing deformation and evaluating the effectiveness of metal forming by explosion.

In samples obtained through deep drawing using explosive forming in a die, the side in contact with the die is more complicated than the inner side, i.e., the side facing the water, which is also understandable. The thickness of the martensite layer on the inner and outer surfaces depends on the detonation velocity. The higher the detonation speed, the thicker the martensite layer, and the greater the hardness.

5 Conclusion

With properly selected technological parameters, the slightest degree of deformation occurs in the normal direction compared to other drawing processes. Due to the high deformation speed, the workpiece's structure remains uniform, resulting from the simultaneous deformation of all zones across the sheet's cross-section.

Therefore, this material-forming technology should not be viewed as suitable only for individual or short-term production; instead, it should be adopted and integrated into the production process wherever possible. For smaller workpieces, explosive forming can even be carried out indoors.

The explosive forming process is most efficiently used for producing large-surface workpieces, where the rated power of conventional machines is insufficient or where acquiring such a machine would be costly. Furthermore, with appropriate tool design, a higher degree of explosive energy utilization can be achieved.

Conflicts of Interest: The author(s) report there are no competing interests to declare;

References

[1] B. A. Tovar, "Explosive Metal Forming," 1973.

[2] D. Šunjić and S. Buljan, "Explosive Forming: Analytical Methods for Determining the Mass of Explosives," *Advanced Technologies and Materials*, vol. 48, no. 1, pp. 9–12, 2023.

[3] A. L. Yarin, I. V. Roisman, and C. Tropea, "Shaped-charge (Munroe) Jets and Projectile Penetration," in *Collision Phenomena in Liquids and Solids*, Cambridge University Press, 2017, ch. V, pp. 515–565.

[4] D. J. Mynors and B. Zhang, "Applications and capabilities of explosive forming," *J Mater Process Technol*, vol. 125, pp. 1–25, Sep. 2002, doi: 10.1016/S0924-0136(02)00413-2.

[5] "NASA Science". Accessed: Jul. 15, 2025. [Online]. Available: https://science.nasa.gov/

[6] E. P. Carton, M. Stuivinga, and H. J. Verbeek, "Explosive forming of aerospace components," in *AIP Conference Proceedings*, American Institute of Physics, 2006, pp. 1249–1252.

[7] J. W. Schroeder, "Explosive Forming," in *Explosive Welding, Forming and Compaction*, T. Z. Blazynski, Ed., Dordrecht: Springer Netherlands, 1983, pp. 347–368. doi: 10.1007/978-94-011-9751-9_9.

[8] C. P. Williams, "Evaluating explosive metal forming," *JOM*, vol. 12, no. 1, pp. 33–36, 1960.

[9] J. Pearson, *Explosive Working of Metals*. New York, 1963.

[10] K. G. Swift and J. D. Booker, *Process selection: from design to manufacture*. Elsevier, 2003.

[11] I. Berman and J. W. Schroeder, "Near-contact explosive forming," 1981.

[12] I. Berman and J. W. Schroeder, *Explosive Welding, Forming, Plugging, and Compaction: Presented at the Pressure Vessels and Piping Conference, ASME Century 2--Emerging Technology Conferences, San Francisco, California, August 12-15, 1980*, vol. 44. American Society of Mechanical Engineers, 1980.

[13] V. Bohanek, M. Dobrilović, and V. Škrlec, "PRIMJENA ENERGIJE EKSPLOZIVA PRI OBRADI METALA.," *Rudarsko-Geolosko-Naftni Zbornik*, vol. 26, 2013.

[14] D. Šunjić and S. Buljan, "Application of Explosives in Metal Forming," in *International Conference "New Technologies, Development and Applications,"* Springer, 2018, pp. 144–148. doi: 10.1007/978-3-319-90893-9_17.

[15] D. Šunjić and S. Buljan, "Determining the amount of explosives in metal forming," in *Annals of DAAAM and Proceedings of the International DAAAM Symposium*, 2019. doi: 10.2507/30th.daaam.proceedings.080.