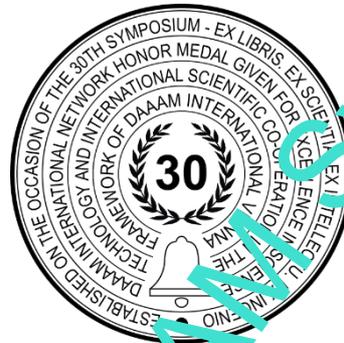


TECHNOLOGIES OF HIGH-VELOCITY FORMING

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Abstract

Technologies of high-velocity forming are mostly used for forming workpieces in which conventional technologies do not have a good effect. It is not possible to form certain workpieces with conventional technologies due to the complexity of the surfaces and shapes, type of materials, dimensions of the workpiece or other technical parameters of the workpiece. Increased market demands, especially in the automotive, aerospace and military industries, have expedited the development of new technologies and thus high-velocity technologies. Some of the technologies which are included in this are explosive forming, electromagnetic forming, electrohydraulic forming, and others. The paper describes these technologies and gives their advantages and disadvantages.

Keywords: unconventional technologies; explosive forming; electromagnetic forming; high-velocity forming; forming

1. Introduction

The development of the technology and industry and the need for the faster production of products with the best possible mechanical properties have conducted to the development of acceptable processes. It has encouraged the constant development and advancement of technique, technology and society itself to evolve from the use of hammers and forging as the first form of metal forming to today's conventional and unconventional technologies and software solutions used in research and work. The need for workpieces with very complex surfaces, different types and thicknesses of materials and enormous dimensions has stimulated the development of new or unconventional technologies that have found their place in metal forming as a response to this need. The technologies and workpieces created by these technologies have the most significant application in the automotive, military and aerospace industries. Titanium and its alloys have one of the best applications in the aerospace industry due to the high strength-to-weight ratio. However, due to the high affinity of titanium for oxygen, hydrogen, nitrogen and carbon, the moulding temperature should not exceed 1000 °C. Therefore, it is challenging for conventional technologies to provide the enormous amounts of energy needed to form titanium and its alloys or similar materials, so a new group of technologies called high-velocity technologies has been developed [1].

According to strain rate, metal forming technologies can be divided into three different groups: quasi-static forming where the strain rates can range from 10^{-2} to 10^2 s⁻¹, superplastic forming from 10^{-5} to 10^{-3} s⁻¹ and high-velocity forming from 10^3 s⁻¹. Conventional metal forming technologies such as sheet metal forming or volume forming belong to the quasi-static forming area, respectively the area of medium deformation strain rate [2]. Technologies of high-velocity forming produce workpieces at room temperatures through the application of a large amount of energy in a very short

time interval, most often milliseconds or microseconds. When the workpiece is formed by high-velocity technologies, kinematic energy is converted into plastic deformation bounded by mould or die. More researches on these technologies were done in the late 1950s and early 1970s although some of these technologies were discovered in the late 1880s.

2. Explosive forming

Indeed, one of the best known, most widespread and most widely used technologies is explosive forming. The difference between this high-velocity forming technology and conventional technologies is that this technology uses explosives as an energy source. The explosive can be used in solid, liquid, or gaseous state. The best-known explosive in the solid-state is the trinitrotoluene (TNT), in the liquid state is the nitroglycerin and in the gaseous state is a methane-air mixture [3]. The explosives that are used in high-velocity forming technologies are called *high explosives*, and very small quantities of these substances are used in the forming process, as opposed to the amounts used in mining or military purposes. Explosive forming is used in combination with deep drawing, compacting, cutting, welding, pipe bulging...[4]. The basic principle in this forming method is that the explosive is placed at a certain distance from the workpiece. The distance and mass of the explosive must first be calculated. Explosive mass can be calculated with (1):

$$G = 0,0113\delta^{0,972}K^{4,134}R^{0,582} \quad (1)$$

where G – calculated mass of explosives, δ – sheet thickness (mm), K – the coefficient of drawing for the blank material and the distance R between the explosive charge and the workpiece. After the detonation of the explosive, the energy of the shock wave forms a metal sheet or a blank according to the shape of the die. In explosive forming, the medium can be in all three aggregate states: gaseous (air), liquid (water, oil) or solid (sand, salt, rubber). [5]. A schematic review of a deep drawing with explosive technology using water as a medium is shown in Fig. 1.

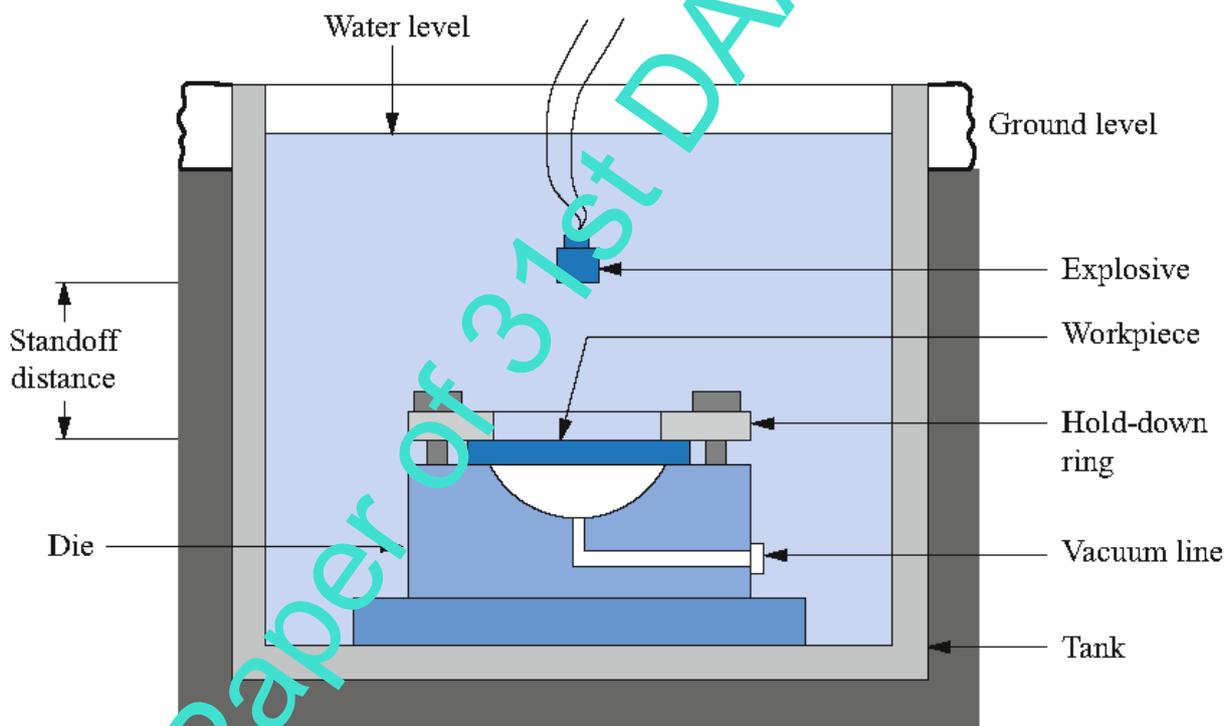


Fig. 1. Deep drawing with explosive [1]

Explosive forming technologies are successfully applied to the forming of metal sheets with a wall thickness of up to 25 mm and a radius of up to 4 m. The mechanical characteristics of the formed workpiece are similar to those obtained by other technologies [6]. Another advantage of explosive forming is its adaptability. Namely, the *female* part of the die can be made of cheaper or easier to form materials (iron, steel, aluminium, concrete, wood) but also of hardened steel if the pressures are higher or a larger number of workpieces need to be processed. The following reasons can be cited as disadvantages of the explosive forming: specially trained and skilled personnel are needed to work with explosives; working with explosives is dangerous; the whole cycle takes a long time [7].

3. Electromagnetic forming

Electromagnetic forming belongs to unconventional metal forming technologies. The energy of the electromagnetic field is used for forming, which is realized by discharging a high voltage electric capacitor. The process itself takes about 0,1 ms. The technology is applied in the aerospace and automotive industries, in the production of refrigeration systems and devices. Electromagnetic forming is performed using the energy of an electric capacitor. The working zone includes the coil, the workpiece and the power supply [8]. The control system regulates the discharge intensity and time, as shown in Fig. 2.

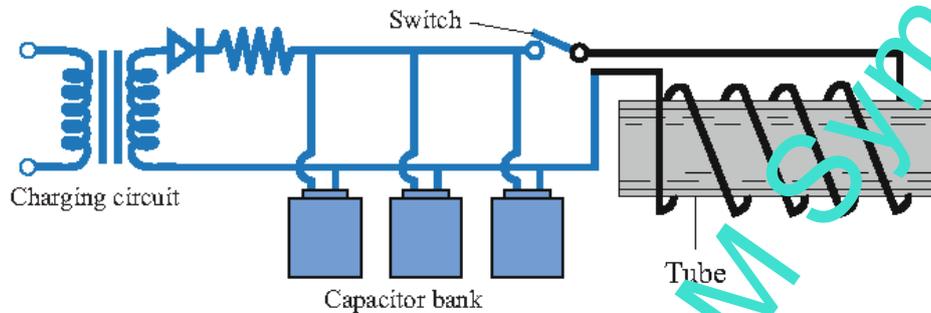


Fig. 2. Electromagnetic forming [1]

Capacitor banks stores the energy which can be calculated from the charging voltage $U(t)$ and the capacity C (2) [9]:

$$E_c(t) = \frac{1}{2} CU(t)^2 \quad (2)$$

This procedure is used for joining tubular or cylindrical bars from different materials, for sheet forming and tube forming. Materials that are mostly used for electromagnetic forming are copper, aluminium or brass. Also, materials with higher electrical resistance can be shaped in this way, using special techniques. In the process of forming using an electromagnetic field, the material can reach a speed of 100 m/s in less than 0,1 ms [9]. The dynamics of the process increases the formability of workpiece and reduces the occurrence of elastic spring back. The electromagnetic forming process can be used for forming sheet metal into very complex workpieces. The characteristics of electromagnetic forming are the following: the conformation of metal materials with high electrical conductivity; high strain rate (up to 300 m/s); contactless forming; absence of heating of the workpiece, it is not needed the use of tools as in classic forming; small elastic deformations are observed.

Electromagnetic forming can be used or performed in three different ways regarding the desired effect. As shown in Figure 3a, the tubular workpiece is formed by placed on another part which is a *grooved* component. In this case, the tube is formed towards the insert. In contrast to Figure 3a, Figure 3b shows the placement of the coil and the cylindrical workpiece within the die and in this method, the tube later expands into the die. Alternatively, a flat coil conductor can be placed above or below the flat surface of the workpiece, as shown in Figure 3c [1].

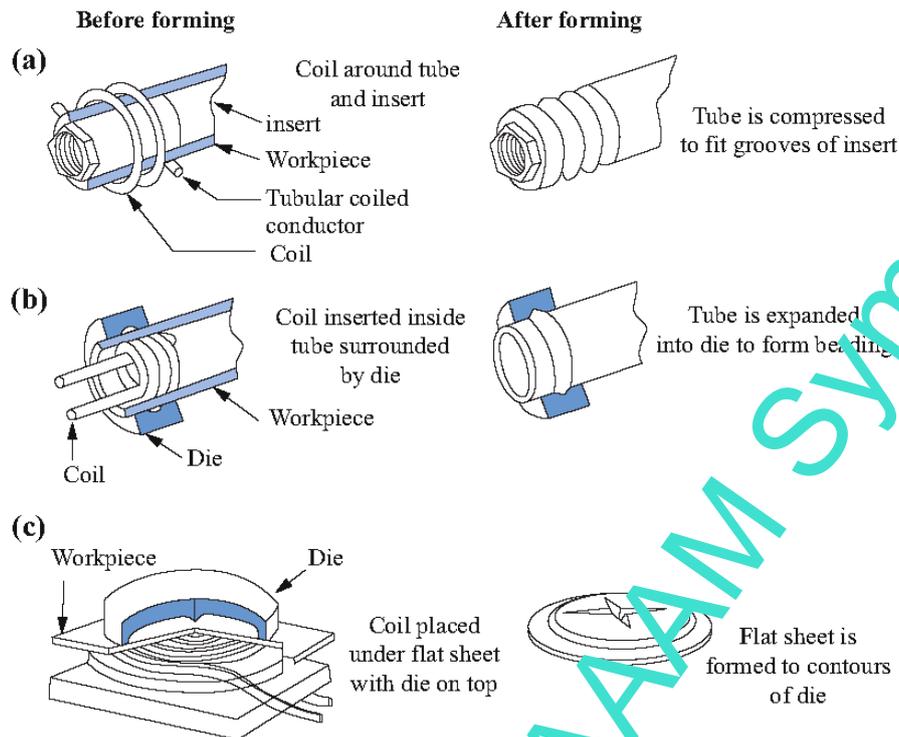


Fig. 3. Example of the use of electromagnetic forming

Electromagnetic forming does not require forming presses or conventional infrastructure. Tools for electromagnetic forming are very simplified because this process uses only one form defining tool and hence the system itself is relatively small and inexpensive. The forming process can be repeated several times. The technology is most commonly used for relatively thin materials with wall thicknesses from 0,25 mm to 1,25 mm. Limitations in the application of the process relate to the electrical conductivity of certain materials so that metals with high electrical conductivity (copper and aluminium) have their application. At the same time, e.g. titanium or stainless steel can hardly be formed with this technology. One of the main problems is the lifespan of the coil used for forming as it becomes unusable due to the large forces impacting on it.

4. Electrohydraulic forming

Electrohydraulic forming is one of the significant and modern sheet metals forming procedures. It is exceptionally economical because it can be used in small series production due to the use of relatively cheap equipment and ability to ensure the accuracy of forming and high quality of formed workpieces. As with electromagnetic forming, with electrohydraulic forming, electricity is stored in capacitors. The procedure is similar to explosive forming. The only difference is in the energy source. In this case, the electric discharge is the cause of the shock wave and hence the amount of released energy is much smaller [1], [10]. Electricity is discharged through a *spark* that is in the working medium, most often water. During the discharge, the water is ionized and evaporates, which result in a shock wave, causing the deformation and consequently shaping the workpiece. Thus, in this case, electrical energy is transformed directly into mechanical energy [7]. Because a relatively small shock wave is generated in this process, it is best suited for forming smaller workpieces, and it is commonly used for forming components up to 0,5 m in diameter. However, it can also be used for forming workpieces up to 1,5 m in diameter. Electrohydraulic forming is characterized by its simplicity and speed, and one of the most important characteristics is that the procedure takes place in one move [11]. To successfully use this shaping technology, it is necessary to know the shock wave fluid pressure, the optimal electrode distance, and the maximum pressure in the fluid shock wavefront. A schematic view of the electrohydraulic forming is shown in Fig. 4.

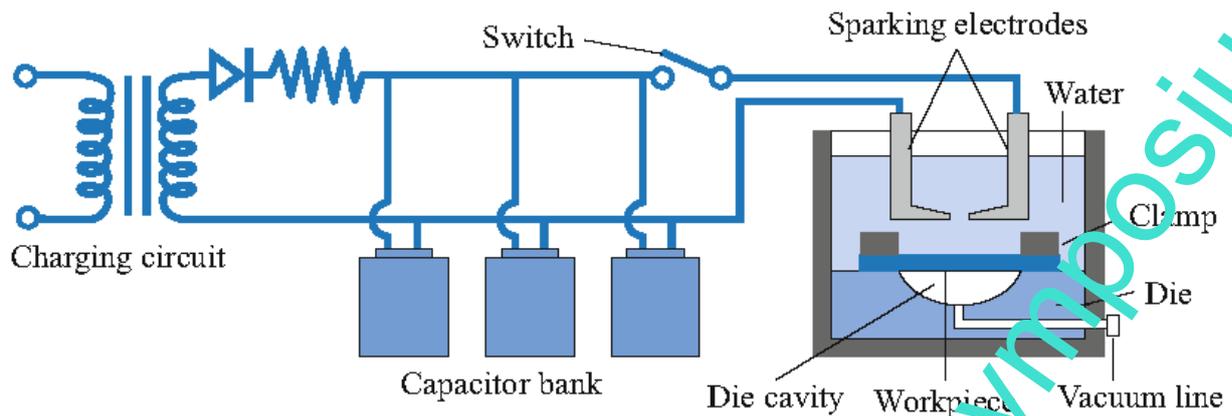


Fig. 4. Electrohydraulic forming [1]

In electrohydraulic forming, two systems can be distinguished, and their use depends on the type of used initiation spark. There is electrohydraulic forming with discharge through a wire (where the electrodes are interconnected by a wire bridge) and electrohydraulic forming with discharge through a gap (where there is no connection between the electrodes). The advantage of connecting electrodes with a wire bridge is that the discharge can be better controlled and formed and shaped so that the process is more efficient and can be controlled at lower voltages and higher distances between the electrodes. On the other hand, this setting requires long preparation of the procedure. [7]. Compared with explosive forming, electrohydraulic forming is more accessible and safer and does not require performance in the remote and isolated areas and uses a smaller tank. This technology can be used to form all materials that can be formed by conventional forming technologies, including aluminium alloys, stainless steel, nickel and titanium alloys.

Electrohydraulic forming is also used to create bulges in tubes. The procedure is performed by filling the liquid in tubes, usually, water, which serves as a pressure transfer medium and the two electrodes are immersed in the water inside the tube. Capacitors, charged with high voltage, are then discharged through the gap between the two electrodes. This spark-shaped electrical discharge creates a shock wave in the water that travels radially in all directions at high speed through the water and hits the inner wall of the tube. The extent of plastic deformation can be controlled by changing the amount of energy released or by placing a workpiece inside the die that will *restrain* the deformation from the outside. [1]. The schematic of this process is shown in Fig. 5.

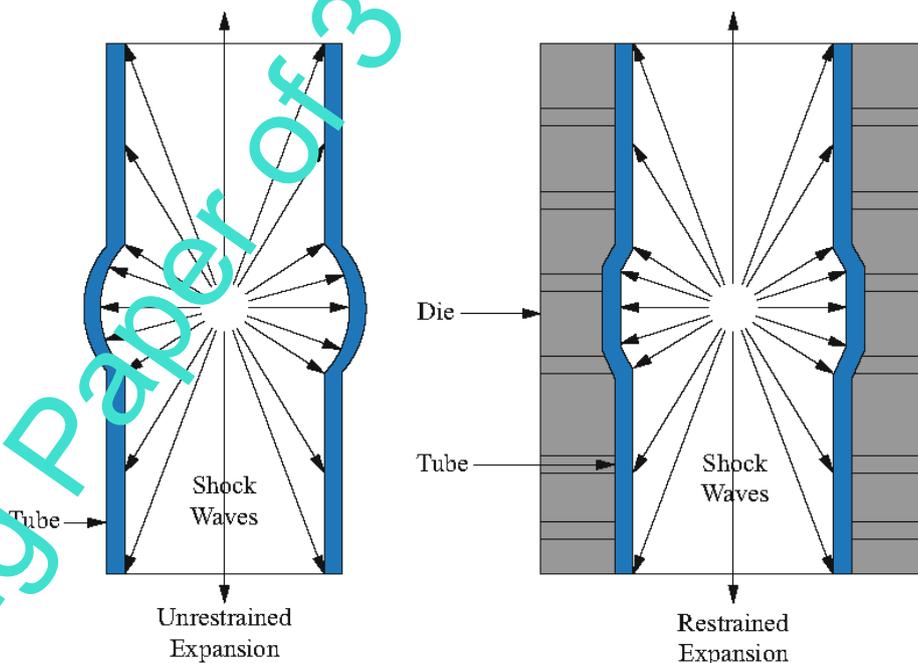


Fig. 5. Electrohydraulic bulging of tubes

5. Conclusion

The development of industry and the constant increase of market requests for manufacturers has also resulted in the development of new technologies in metal forming. These requests may relate to the forming of workpieces with larger dimensions, larger wall thicknesses, to the forming of materials that are difficult to form by conventional technologies or materials that require high temperatures to form correctly. Due to high stresses in high-velocity forming of metals including aluminium alloys, magnesium, titanium, a better formability's can be achieved. Also, in these technologies, the effects of wrinkling and elastic springback are reduced, and due to the very short duration of the process, they are considered adiabatic so that heat can be better used for forming, unlike conventional technologies. The advantages of high-speed technologies also lie in the fact that the final dimensions and shapes can be obtained mainly from a single operation, thus avoiding tools and intermediate steps; tool costs are reduced due to the use of the *female* part of the tool; workpieces can be made with narrow dimensional tolerances due to a significant reduction in elastic springback; processes of high-velocity forming can be performed without polluting the environment because air or water can be used as media and the use of lubricants or oils is reduced, and it is almost irrelevant for the processes. In addition to these advantages, of course, there are some disadvantages of these technologies, so we can list some of them: specially trained and educated staff is needed; brittle materials are more difficult to form; uneconomical process for mass production.

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