Mathematical Modeling of Impulsive Forming Processes Using Various Energy Sources and Transmitting Medium

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Abstract

High-speed forming uses high explosives, gun powder, combustible gas mixes and compressed gases as sources of energy. Special mathematical models are used to take into account specific dynamic properties. Different technological processes of forming have been modeled in the work. They use liquid (water), elastic (polyurethane), and gaseous transmitting medium. The difference between impulse energy transference, load distribution on a blank and tool surface, and also wave propagation is shown for used transmitting medium. The developed procedures allow taking account significant thermal effects at adiabatic compression of the material and heat transference directly from products of explosion. Specially developed modules and mathematical models have allowed the application of standard software products for modeling high-speed forming and sheet metal punching processes.

Keywords:

Sheet metal blank, Explosive forming, Hydro-impulsive forming, Gas detonating forming

1 Introduction

Mathematical modeling of high-speed processes is widely used at the present time. Simulation represents the effective tool to study high energy forming processes. High-speed physical experiments are provided with special expensive engineering and measuring equipment. Therefore, the analysis of complex technological processes on models is cost efficient; it gives more information about the process and allows determining influencing parameters.

The majority of the commercial software products used for modeling of traditional technological processes of sheet metal forming and punching of thin-walled tubes (shells) is inapplicable for calculation of high-speed processes. They do not take into account specific dynamic effects. Neglect of mass forces, dynamic properties of materials, temperatures, dynamic friction, etc. leads to essential errors in calculations.

2 Mathematical modeling of high-speed forming technological processes

There are some special software products in the field of high pressure, defense and airspace techniques allowing precisely calculate wave processes, high-speed deformations in material and medium. However, these programs are not adapted for calculation of forming technological processes; therefore, it is necessary to adapt these special programs to solve new technological problems of sheet metal forming.

The commercial software code AUTODYN® of the Center Dynamics has been selected as the base product. The University Otto-Von-Gericke, Magdeburg, has long-term experience regarding to the use of this code for studying the explosion phenomena. Specially developed mathematical models and code modules have allowed to apply the AutoDyn program for modeling of sheet metal high-speed forming and punching processes.

Various sources of energy are used for high-speed forming [1, 2]. The most common of them are:

- High explosives using for explosive forming;
- Compressed gases using for solid body impact forming and
- Combustible gas mixtures using for gas detonation forming.

The listed above sources of energy have different initial density of energy, speed of discharge of the internal energy, developed shock wave peak pressures and temperatures.

In the given work, results of mathematical modeling of different technological processes are submitted. They are explosive forming, forming by solid body impact, and gas detonation forming.

2.1 Modeling of explosive forming processes

Essence of explosive forming consists in transference of explosion energy generated by an impulsive source of energy to a metal preparation (blank) through a transmitting medium. The basic set-up for explosive forming of parts from a flat sheet blank (Figure 1) consists of a basin with a transmitting medium, a die with clamped sheet blank, and a charge of impulsive energy.

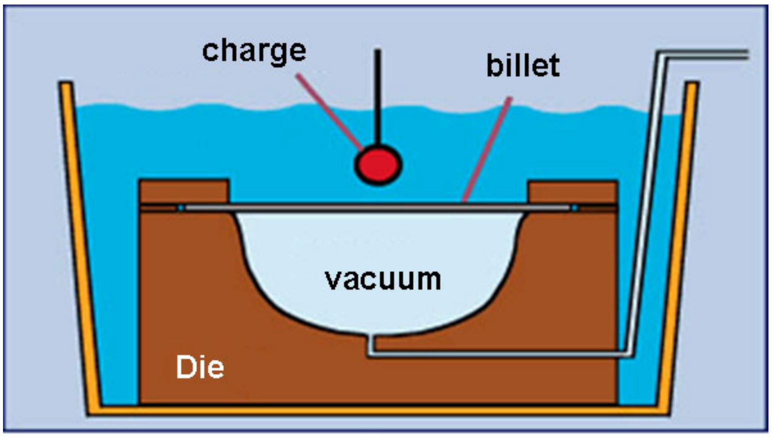


Figure 1: *Set-up for explosive forming of sheet metals*

Charges of simple forms are used: spherical (Figure 1), cylindrical, or cord type. The transmitting medium as a rule is liquid, gaseous, loose powder, jelly, or elastic. Technical water is used as the liquid medium, humidified sand is used as loose medium. Explosive forming is carried out in stationary, reusable pools or in a destroyed micro-basin.

Results of numerical simulation of explosive forming processes show that the most important factors of the production technology can be modeled using noted special software products. They are:

- Shock waves distribution in transmitting medium (Figure 2a)
- Gas bubble formation during forming process (Figure 2d)
- Die and technological equipment elements presence (Figure 2b, Figure 2c)

Specific feature of explosive forming, in comparison with "classic" methods of forming, is presence of direct and reflected shock waves in the transmitting medium. High pressure shock waves move through the transmitting medium. They move successfully through the continuum, increase on rigid surfaces, but reflect with negative stress from flexible and free boundaries. Therefore in the transmitting medium local zones with negative stress are formed. The transmitting medium (technical water) maintains a low negative stress (some units only). It leads to formation of gas-filled micro-cavities inside the transmitting medium (see Figure 2c, 2d). Properties of these discontinuity ("boiling") zones are very different in comparison with the continuum media.

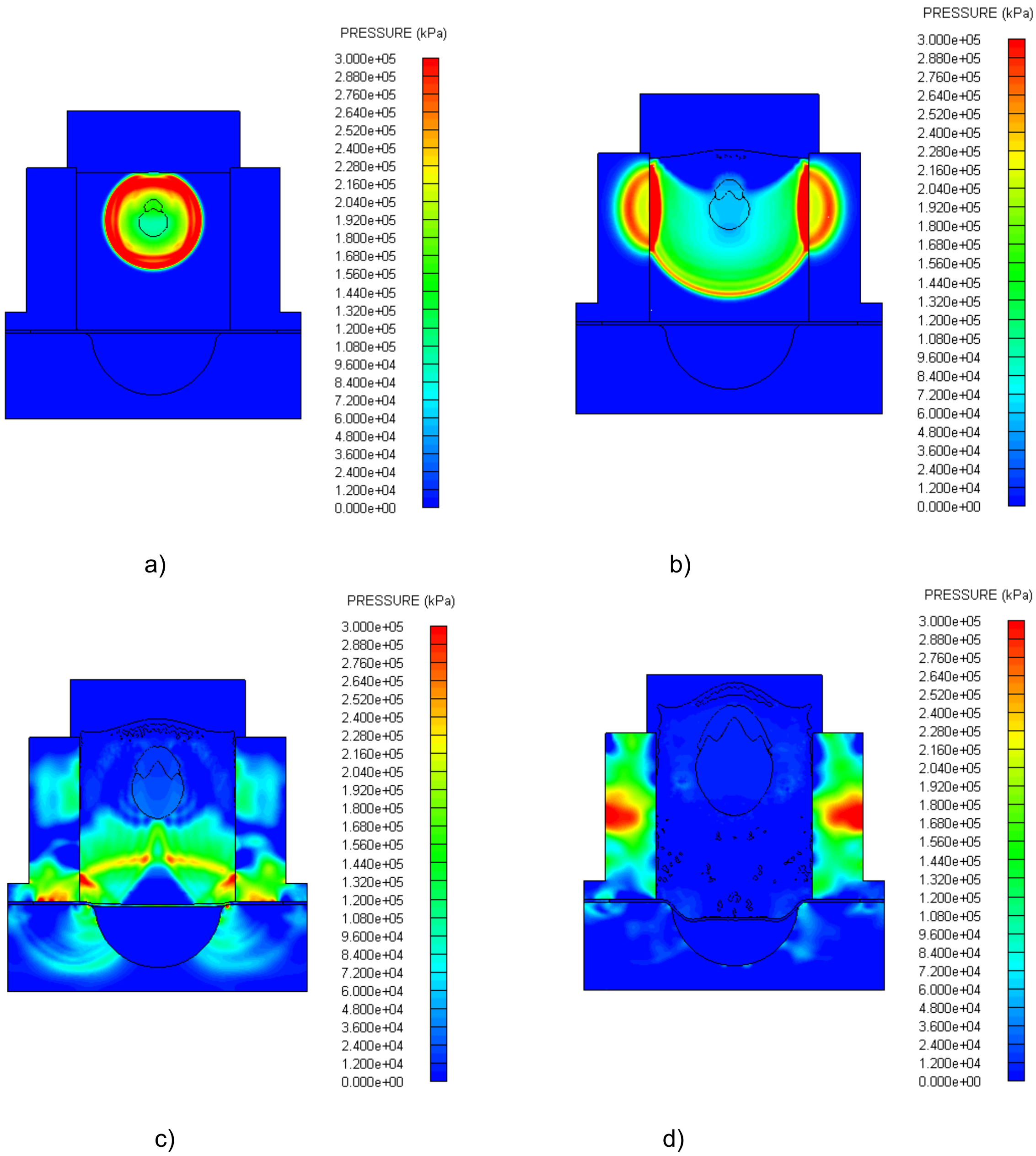


Figure 2: *Stages of calculation of explosive forming using a rigid micro-basin*

Cavitation essentially affects the pressures generated in the transmitting medium. Hence, numerical modeling of explosive forming has to take into account cavitation effects.

2.2 Simulation of the forming process by solid body impact

A basic set-up for forming using solid body impact energy is shown in Figure 3. A solid cylinder accelerates in the special thick-walled tube by a source of energy. Impact of the noted solid body with the transmitting medium generates shock waves. These shock waves deform the blank to the die cavity.

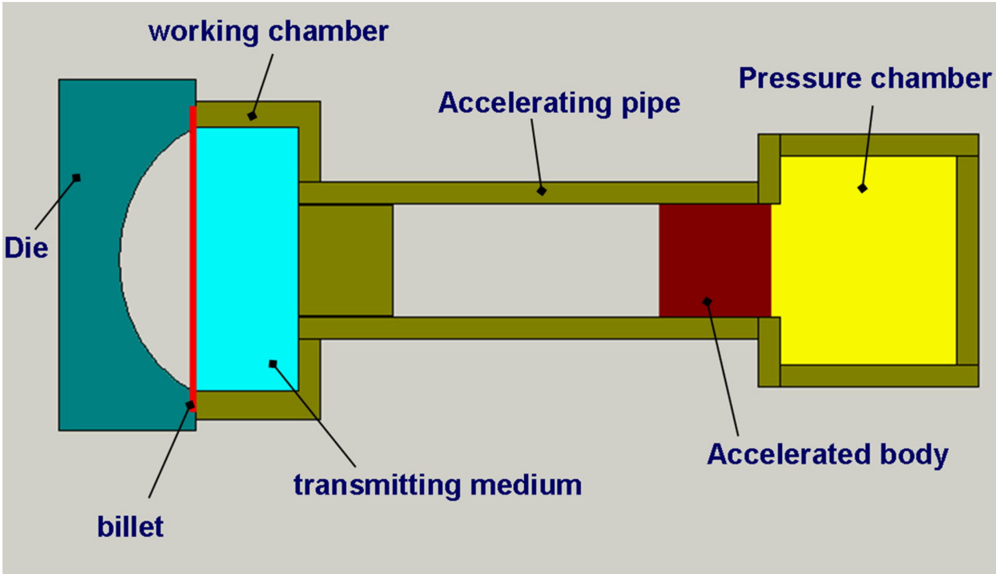
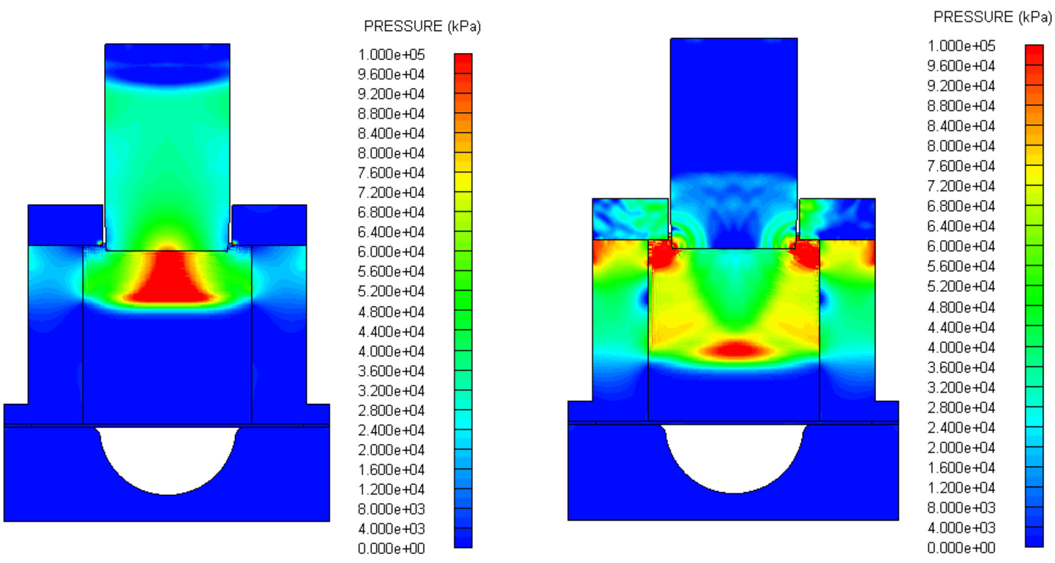
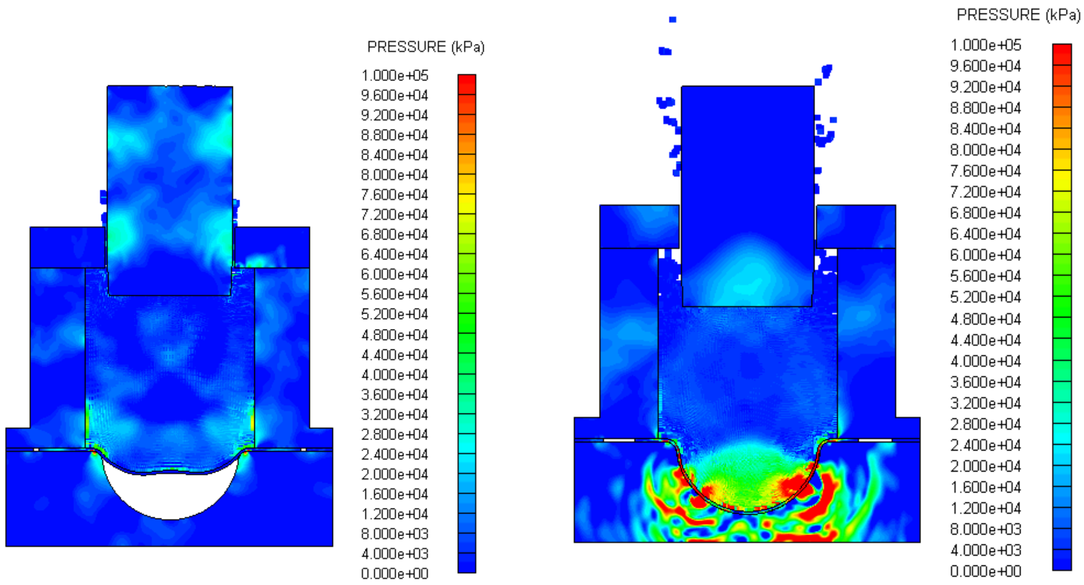


Figure 3: *Set-up for thin-walled part forming using an elastic medium*

An example for a forming process simulation of a hemispherical part has been provided. The blank was sheet steel (type QStE340) with diameter 200 mm and thickness 1 mm. The transmitting medium was elastic medium (polyurethane). Results of the numerical modeling are submitted in Figure 4.



a) b)



c) d)

Figure 4: *Sheet-metal forming using solid body impacts*

Figure 4a shows a solid cylinder impact with the transmitting medium. Shock waves are generated. Figure 4b – Figure 4c shows distribution, reflections, and evolutions of shock waves in the cylinder, die, working chamber, and in the semi-product. The deformation of the workpiece during forming is irregular, as against of static methods. Wavy character of the work piece deformation is caused by plastic waves expanded in the blank during forming.

2.3 Modeling of gas detonation forming

Figure 5 shows a set-up for gas detonation forming.

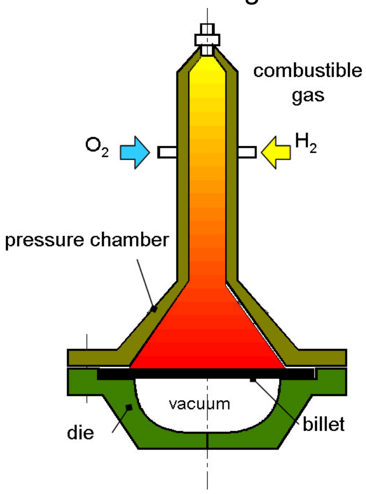


Figure 5: *Set-up for gas detonation forming*

There is a strong compression of the hydrogen-oxygen mixture in the shock wave at gas detonation forming. The temperature grows sharply and the pressure wave transforms to the detonation wave in the gas mixture. In this method, the energy which is necessary for shaping, is generated by a chemical reaction in the gas mixture. External pressure for forming generates by gas detonation wave. Therefore, the calculation of burning processes in gas and transition from burning to explosion is the important for numerical modeling of forming process.

Figure 6 shows shock waves evolution in the tube at gas detonation. Repeated reflected shock waves are visible. The reflections of shock waves lead to pressure, temperature and speed increase in the shock waves during deformation. This is the reason why to take into account dynamic effects is very important. The factor of reflection has essential influence on the results of forming process numerical simulation.

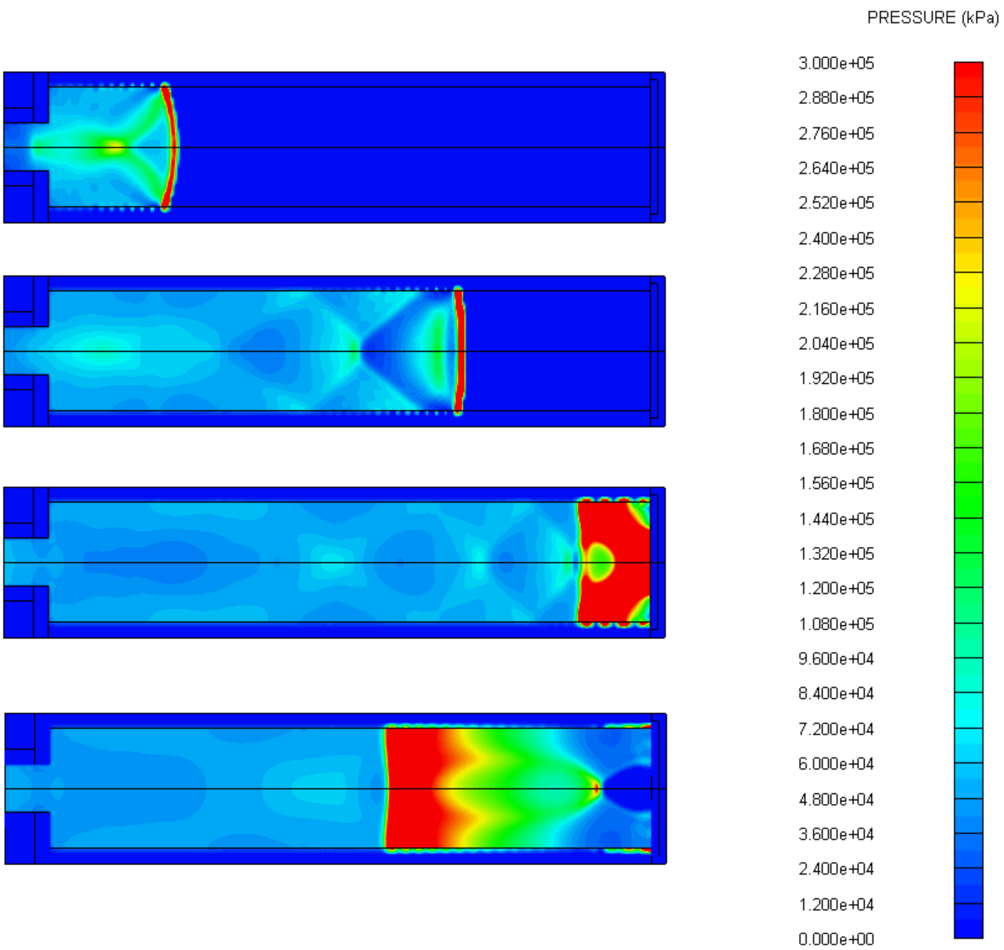


Figure 6: *Shock wave evolutions and reflections during tube expansion*

3 Technological features of high-speed forming

Some materials at high-speed forming have a higher plasticity. This effect is observed in the limited range of deformation speeds. At designing of new technological processes dynamic properties of materials have been accounted. Loading speed was defined by the amplitude-time characteristics of the impulse. Figure 7 shows how the impulse profile effects the part profile.

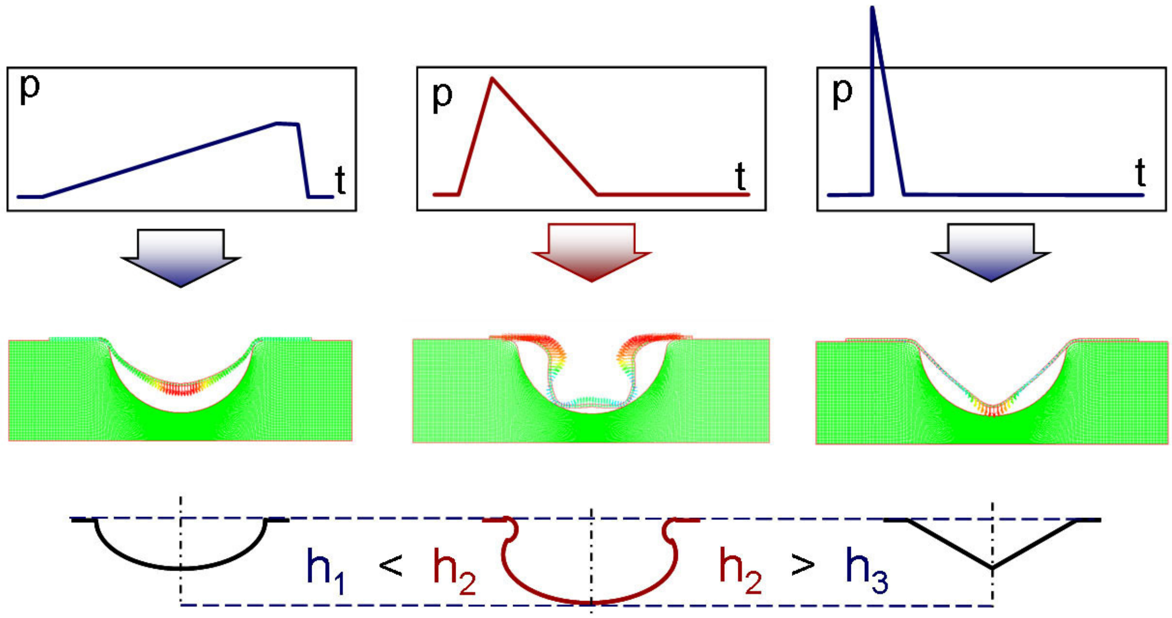


Figure 7: *Influence of impulse parameters on the form of preparation*

The temperature of the preparation during explosive forming is increased. This is due to adiabatic compression in the elastic - plastic wave moving through the blank. Figure 8 shows areas with such thermal effects. They are located in the bottom of the part and near the drawn-out edge. It has been established that the temperature increase depends on material properties, speed of deformation, and thickness of preparation.

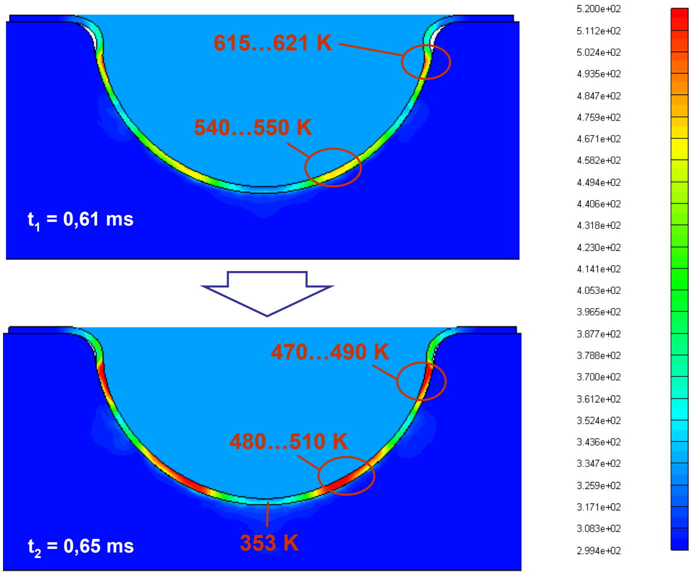


Figure 8: *Thermal effects at high-speed forming*

Figure 9 shows how mass distributed forces influences on the character of deformation. These forces can be positive and useful increasing the flange displacement at deep drawing. Nevertheless, they can be negative generating corrugations on the flange if excessive value [3,4]. Right impulse value and flange friction after simulation have been received.

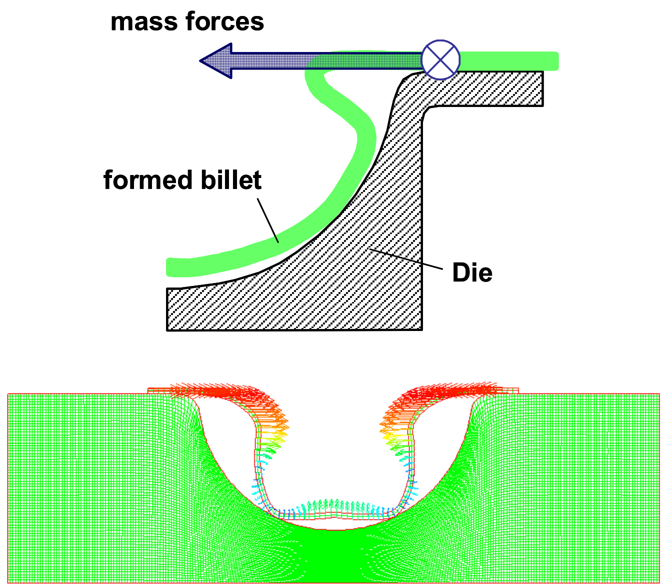


Figure 9: *Flange displacements due to mass forces presence*

4 Conclusions

In the work, transfer of impulse energy, distribution of loading on a blank and die, and wave processes in various technological methods are shown.

Influence of the form of an impulse and properties of the blank material on the final form of the stamped detail is shown.

The developed models allow taking into account dynamic effects such as cavitation, distribution, reflection and imposing of intensive shock waves to preparation, equipment and the transmitting media.

Calculations are carried out with the account of thermal effects at adiabatic compression of a blank material and direct heat transference from explosion products to the blank.

Optimum selection of amplitude-time characteristics of a pressure impulse provides maximum use of the materials deformation ability.

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