APPLICATIONS OF MANUFACTURING TECHNIQUES AT ELECTROHYDRAULIC IMPACT FORMING OF SHEET COMPONENTS WITH COMPLICATED LOCAL ELEMENTS

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Abstract

Forming of components from high-strength and thick-sheet materials (4 mm and more) is a problem for method of electrohydraulic impact forming (EHF). Difficulties are connected with forming and calibration of elements of large curvature, if characteristic radius is less than 10 thicknesses of blank. At this approach sheet is considered to be thick when its thickness is less than 4 mm, and strain-stress condition is not plane, but volumetric one (cubic strain).

Forming of elements of large curvature needs high contact stresses to be developed by high local loads that are a problem at large distance to discharge channel.

The following manufacturing techniques were analysed: concentration of energy by cumulation in gas cavities; concentration of pressure with aid of electrode pairs of directed action; application of specially-shaped wires; application of intermediate plate at the stage of formation of general shape (deep drawing); application of elastic pads on large-curvature surfaces; sequent application of die and punch; local heating of sheet blank at sequent stages of forming process.

Tests results on experimental forming of sheet components with complicated local elements are submitted. They give the numerical values of ranges for applications of various manufacturing techniques.

KhAI EHF laboratory continues investigations to improve processes for small and middle-batch production of sheet components of complicated shapes from various wrought materials.

Keywords: forming, impact, electrohydraulic, manufacturing, sheet metal, curvature

1. ANALYSIS OF PROBLEM

Diagrams of electrohydraulic impact forming are famous and successfully applied for manufacture of wide variety of sheet components. Typically they include one rigid tool – die or punch, hold-down plate and discharge chamber. Forming process can be realised with elastic diaphragm to prevent contact of water with a sheet blank surface (dry process) and without diaphragm to improve efficiency of electric energy transformation into energy of plastic deformation (wet process).

Many sheet parts are of very deep shape or may include local elements (ribs, bosses, small-radius corners, dimples, etc.), which are impossible or very expensive to produce with traditional EHF diagrams. In order to produce parts with such difficult elements with high efficiency the manufacturing (technological) techniques are applied.

Manufacturing techniques are the methods that allow to improve a forming process with application of low-cost (as compared with cost of main tooling) additional tools, pads, spacers, modifications of main tooling, better organisation of forming process.

Purpose of this work is to investigate applications of several manufacturing techniques and develop recommendations for their use in EHF processes.
2. TESTS RESULTS

Tests were carried out in technological block of experimental electrohydraulic installation UEHF-2 equipped with 52-electrode discharge block (Fig. 1). Energy is supplied to electrodes from 22-contour generator of impulse current with work voltage up to 40 kV [1].

2.1 Application of intermediate plates

The problem in forming of deep corner elements of box-type sheet components is excessive thinning and fracture of sheet metal with development of forming process. It was noticed when blank touches to the die bottom a deep-drawing process and pulling a flange into die cavity nearly stops. Forming of corner element occurs at the expense of stretching of blank segment that is not in contact with die surface (Fig. 2). Curve shown in Fig. 2b is plotted at the following assumptions: 1) forming of corner element occurs gradually in several steps (typically EHF is performed in several discharges) with increments $\Delta h$ along side wall of die and $\Delta l$ along bottom; 2) segment of sheet blank is an equilateral triangle and basis of pyramid with vertex in bottom corner (near to radius $r$); 3) for each forming step initial area equals area of equilateral triangle $A_i$ and final area equals area $A_{i+1}$ of side surface of truncated pyramid and equilateral triangle in total; 4) volumes of metal in deformation are equal for start and final moments of a deformation step; 5) thickness of a deformed segment of blank $t_i$ and $t_{i+1}$ is uniformly distributed along areas $A_i$ and $A_{i+1}$, respectively.

It is obvious (ref. Fig. 2b) that for deep corners a sheet metal rapidly exhausts its plasticity, because of concentration of deformation in a rapidly decreasing area, and fracture happens. This theoretical analysis is many times confirmed by practice of EHF of box-type sheet parts.

Here the application of intermediate deep-drawing plate is reasonable. The idea is to pull enough quantity of sheet material into die cavity for further formation of corner elements. Deep-drawn semi-product has

![Fig. 1. General view of multi-electrode discharge block of the UEHF-2 electrohydraulic installation](image1)

![Fig. 2. Schematic diagram for forming of corner element (a) and dependence of relative blank thickness $t/t_0$ from relative depth $h/r$ (b): 1 - corner fragment of die; 2 - sheet blank; 3 - hold-down plate; 4 - plasticity limit of low-plasticity metals; 5 - plasticity limit of high-plasticity metals; $t_0$ - thickness of sheet before start of forming corner element; $r$ - die bottom radius](image2)
height larger than the final shape (Fig. 3). During next manufacturing step blank material is redistributed and fills corners without fracture. At final stage excessive quantity of material along bottom is pressed to the direction corner (ref. Fig. 3b and 3c).

In order to facilitate deep drawing of corner segments another technique is also applied. Radius of die drawing rib is made here larger as compared with straight segments, where larger resistance for deep drawing is desirable to stabilise the process. Both techniques allowed to tune EHF process for production of box-type part (Fig. 4) from high-strength aluminium alloy AMg6 of 2 mm thickness.

2.2 Application of elastic pads

Pads are recommended for use when radii of local elements are very small and they cause fracture of sheet metal along such radii because of concentration of tensile stresses in combination with bending stresses.

Typically such local elements are bosses or bottom depressions (dimples, grooves) with small radii (equal to 1 to 5 thickness of sheet blank). Purpose of pads application is to accumulate blank material around difficult element by pre-forming of preliminary shape of this element and, thus, reducing tensile stresses at final forming.

For example, in the die shown in Fig. 1 a box-type part is formed from aluminium sheet of 2 mm thickness. There are 3 bosses with radius of 4 mm, equal to 2 material thicknesses (Fig. 5). At the stage of forming of local bottom elements sheet aluminium fractures along these radii.
Application of rubber pad of 5 mm thickness placed on boss enlarges radii and sheet material around the boss (Fig. 6). This material is in suspended condition before final calibration and so it easily deformed and pulled to bottom radii of boss.

In order to avoid wrinkling because of compression stresses at the stage of final forming it is recommended that final shape should be (2-5) % more than pre-formed shape. In our case the final shape with nearby blank segment has area of 7760.7 mm$^2$ (ref. Fig. 5a) and preformed shape is of 7644.7 mm$^2$ (ref. Fig. 6a and 6b), that is, difference is just 1.52 %. This feature allowed to perform final boss shape without cracks and without significant change of a hole shape (ref. Fig. 5c). This means that stresses in sheet material were enough for deformation, but less than destructive ones.

The holes were drilled to facilitate deformation process and reduce stresses along upper boss radii. Holes are permitted by design of this box-type part.

### 2.3 Sequent application of die and punch

When making forming of hard-to-deform materials or sheet of large thickness with EHF method there is a problem to produce small-radii elements. In these cases the manufacturing technique of sequent application of die and punch can be technologically and economically reasonable.

For example, in production of round profiled part (Fig. 7a) from carbon steel of 2 mm thickness the problem was to provide small radii of 6 mm. That is, radii equal 3 thickness of sheet. Here the bulk stress-strain condition should be considered, not biaxial one. Upper radii of 4 mm are relatively easy obtained at impact loading. But in order to form the small bottom radii ($R_1$ and $R_2$ in Fig. 7a) the concentrated forces should be applied (Fig. 7b) at the stage of calibration and, hence, traditional punch-and-die stamping method. But
Fig. 8. Diagram of required distributed pressure loads $p$ at calibration stage on punch-type tool (a) and general view of finally formed product (b)

Traditional tools are several times more expensive in comparison with EHF tools.

The solution of this problem was in application of punch-type tool (Fig. 8). Here the distributed pressure load $p$ is applied to large area of preformed blank and, thus, creating large forming force that concentrates along small contact surfaces. The large force generated by relatively low pressure $p$ is able to produce bulk deformation and form final radii $R_1$ and $R_2$. Here the peripheral force $F$ is created by hold-down ring.

3. DISCUSSION OF TEST RESULTS

Results of conducted tests showed that many sheet parts of complicated shapes with difficult local elements are impossible to be produced with traditional EHF approach. This is because of several peculiarities of impact nature of loading and properties of elastic medium (water) for transmitting a loading impact. These peculiarities determine mechanism of sheet blank deformation that differs from deformation mechanism with rigid punch and die loading.

Though application of intermediate plates for deep drawing is also famous in traditional punch-and-die stamping, EHF method has peculiarity in the next step of forming and final calibration of local elements. Also making a drawing radius with varying value along contour of die or drawing plate is also famous to regulate resistance of certain blank flange segments for deep drawing. Here literature sources give recommendation for selection of die drawing radius $r = (5...10)t$, where $t$ is a thickness of sheet metal. This recommendation does not take into account other important factors that influence a stability of deep-drawing process (to avoid flange wrinkling and folding): depth of a formed part and radius of die cavity in plan of die (top view).

Analysis of the tests results obtained by the KhAI EHF Laboratory allowed to propose the following dependence to calculate maximum value of drawing radius

$$r_{\text{max}} = k \cdot \frac{t^3 \cdot R}{H},$$

where $t$ is a blank thickness, mm; $R$ – radius of die drawing rib in plan, mm; $H$ – depth of die cavity, mm; $k = 20 \text{ mm}^{-2}$ – coefficient.

The value calculated from the above formula is a maximum limit value that allows to perform deep drawing process without folding, small wrinkles are ironed by a drawing rib when flange goes into die cavity. Also it operates when width of bank flange is minimal and its edge stops (at finish of deep-drawing process) at the initial point of radius $r_{\text{max}}$.

Application of elastic pads is effective and inexpensive method for manufacture of sheet components with local elements with high quality under small-batch production conditions. But their use is not limited by only local elements. For box-type parts the problematic corner elements can be performed with additional amount
of material accumulated with a large profiled pad laid on the die bottom, that is, realisation of forming diagram similar to Fig. 3b and 3c.

Sequent application of die and punch tools proved to be effective for sheet metals of big thickness, high strength and low plasticity.

Technique of energy concentration by cumulation in gas cavities is effective for had-to-deform metals, when producing relatively small local elements. But gas cavities often are not convenient for mounting is a discharge chamber. Their application greatly increases preparatory period for forming process.

Concentration of pressure with aid of electrode pairs of directed action allows to increase 1.2–2 times shock wave pressure and 2–4 times impulse of hydraulic flow. These improvements are due to reflecting and directing surfaces located around electrodes and spark gap. But such electrode needs some mechanisms to position them in proper places along a blank surface.

Application of wires for stabilisation of electric discharges and control of pressure fields is very positive method [2]. But it needs relatively long preparatory period before forming process. Also there are no reliable mechanisms to feed a wire into spark gap.

Heating of sheet blank at sequent stages of forming process includes several aspects: annealing of all blank at some stage of forming process; annealing of separate segments of preformed blank (local annealing) to facilitate further forming; forming of entirely preheated blank of low-plasticity metal; local heating of certain segments of blank to facilitate deep-drawing process or forming a local element with large curvature.

4. CONCLUSIONS

Applications of manufacturing techniques mentioned above allow significantly widen technological capabilities of EHF method to provide manufacture of high-quality sheet products.

In cooperation with partners the KhAI EHF Laboratory carries out investigations for improvements in the manufacturing techniques regard to various general shapes of sheet components and various metal materials.

LITERATURE
