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METAL-EPOXY-CONCRETE DIES FOR EXPLOSIVE FORMING

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Abstract: *In our search for die-materials that are not restricted by limitations of size, in the process of producing sufficiently large masses by explosion forming, we have adopted a form of construction in which epoxy-faced concrete is used for the die-cavity. This kind of technique is used to make a plaster master of the die-cavity, which is then coated with epoxy resin, reinforced with fiber glass. An adequate amount of reinforcement rodding and steel plates has its place in construction. The method of making dies for large and complicated components, using the explosive- forming technique is described here.*

Key words: *explosive forming, die for explosive forming, underwater explosion, concrete die, epoxy resin.*

1. INTRODUCTION

To find the optimum parameters for explosive forming new parts, a theoretical analysis is necessary, as well as the experience gained from previous programs. These ones offer some general guidelines and some limits which restrict the search area.

There are many problems associated with explosive forming- dies. One of this problems is the time needed to load and unload the die. A vacuum must be maintained between the part and the die to prevent air compression in the die. The need to release this vacuum has led to complication in explosive-die design and to sealing problems that have slowed down the handling procedure [1–3].

Another problem for explosive forming is choosing the die-materials. We consider that ductile iron has the best characteristics for the process, but as the size of parts increases, the cost and problems involved in handling become significant.

2. FIELD ACHIEVEMENTS

There have been made some interesting analyses, trying to find out a technical answer to this problem, and the results were different.

Using the concrete was a successful solution, for developing some large-sized metallic parts. The problem was the relatively short life of the die. The stresses produced by the shock waves that were reflected on the interfaces of the buffer materials, can lead to a fast breakdown of the dies surfaces. Therefore, a match of the acoustic impedance between concrete and the material supporting the concrete is necessary. Many successful results have been obtained in using this kind of dies for 3.6 m diameter caps forming, for Skylab II. However, when the concrete is used, the control of the parts shapes is less precise, and the die life is limited compared to that of the solid metal die. The experience gained showed that, for a limited edition, of 10 to 20 parts – the concrete can be efficiently used.

For larger parts, with dimensions between 2.5–4.5 m, using the dies made of steel, concrete, kirksite or similar materials, can lead to logistics problems, and the costs of the dies are high. Thus, the concepts regarding the tooling must be developed, which would significantly decrease the die weight, allowing a more efficient handling and transportation. At the present, there are two methods that are really hopefully in the weight decrease and costs reduction: encased plastic dies and metal foil dies.

The plastic tooling is used on a wide range in automotive industry, for sheet metal parts, for some pressed parts, hydroformed or using some other methods. Regarding the explosive forming, the plastic tooling gets little attention, the most forming operations being performed on small dies, between 0.3 and 0.6 m in diameter. An intermediate solution is: dies made of reinforced concrete, poured in metal cases, coated with a plastic material (epoxy resin), below mentioned type.

An interesting structure was the die made for large parts forming, of fiber glass and resin, attached to a wooden external gauge. The die cavity, together with the clamping flange, are fitted on a supporting steel structure; under the steel loop, coil springs and wooden shock structures are used, to reduce shock amplitude on the self-supporting platform and to prevent the hollows occurrence during the forming operation. On this die there have been realized two domes made of 2014 aluminum, 3.048 m in diameter and thickness of 19.05 mm each; a single detonation was produced, using 12 kg pressed loadings, containing RDX explosive. Even if there were some problems in using the die and the tooling life was limited, this concept represented an important trial, regarding the capability of the conformation with the manufacture requirements. The tooling cost was less than half of the steel dies cost, and the gross weight was decreased from more than 60 tons to less than 30 tons.

Thin-walled case dies, made of metal, as well as plastic, are using the fact that water is essentially an incompressible liquid and can be effectively used at supporting the thin-walled cases, in which the metal sheet is formed. From here, two basis methods appear: (1) a pendular system, with the die suspended in a liquid environment, and the draw ring being normal on the liquid surface and (2) a solid base of the die, containing a water insertion. The case-die concept was used a few times, and a complete estimation of the systems is not completed.

Another idea was using the ice as a forming ground. Although the idea was good, there have been some difficulties in maintaining a right direction of the perimeter, and the errors led to the gauge bending, because of the defective support of the blank. However, the capability of easily changing the shape, of making the needed repairs and the easy handling of the dies represent important advantages. This method is still used in Germany, where, for consolidating the strength and for increasing the ageing of the ice dies, different dispersers are used.

Free forming can be the answer! The ideal solution for forming large parts is to totally eliminate the die. A lot of work has been done for free explosive forming, without using the die cavity. However, a supporting structure, a draw ring and a clamping ring are necessary. The control over the shape tolerance, using the above method, is not good; the shape of the part can be precisely established only when the explosive loading shape, density and location on the blank are exactly known and controlled. For parts having the diameter of 3–4.5 m, there are not enough savings made, regarding the weight and costs, using the free forming method, for justifying the disposal of the die cavity, and killing the part tolerance and the shape accuracy.

3. DIES CONSTRUCTION

In our search for die-materials that are not restricted by the limitations of size, in the process of producing sufficiently large masses, we have adopted a form of construction in which epoxy-faced concrete is used for the die-cavity. The technique that we use begins with making a plaster master of the die- cavity. The plaster model can be obtained either by copying the original part, when a drawing does not exist and its scaling is difficult, because of the complexity of the part, or by processing the plaster on numerical machines. The latter case is the most frequent.

This master is then coated with epoxy resin, reinforced with fiber-glass, having a thickness of approximately 1 cm. A metal box is placed over the master. An adequate amount of reinforcement rodding is placed inside the section so created and a high strength lightweight concrete is poured into it to make the die. When the concrete has set solid, the concrete with the epoxy-resin facing, attached to it, is removed from the plaster master. It is important for the die to be used after a certain period, of minimum 25 days, necessary for the concrete to get to the maximum strenght, to avoid the breakdown of the assembly, that may emerge from the dynamic loadings that appear during the explosive forming.

Fig. 1 shows the plaster male model of the die-cavity, which is coated with epoxy-resin. The metal box placed over the plaster model serves as a shutter and it is prepared for pouring of the concrete. Inside the metal box is placed the reinforcement rodding (Fig. 2). In this stage, we must not forget that, regarding the large parts, when

Fig. 1. The master coated with epoxy resin reinforced with fiber-glass.

Fig. 2. Reinforcement rodings placed inside the metal box.

the air volume beneath the blank is appreciable, a special, sealed pipe is needed, to allow the vacuum of the enclosure. This pipe is usually clamped in concrete and must be located so that to avoid the impact deformation or the breakdown during the handling.

One of the ways of bettering the concrete characteristics is the use of synthetic resins for cement. Table 1 shows a comparison between a normal concrete and three marks of concrete with synthetic resins: concrete with epoxy-resin, concrete with metacrylic-resin and concrete with unsaturated polyester-resin.

Table 2 presents the representative mechanical characteristics of unsaturated polyester-resin type NESTRAPOL 220 [4], with and without fiber glass reinforcement.

Analyzing the values of Table 2, we observe that plastic materials reinforcement leads to a substantially growth of these physic-mechanical characteristics.

Table 1

Characteristic values for four concrete marks [4]

Material characteristics	Concrete with		
	Cement B 500	**Epoxy resin**	**Metacrylic resin**
Density [kg/dm^3]	2.4	2.24	2.3
Elasticity modulus[KN/mm^2]	30	32	38
Compressing strength[N/mm^2]	30	100	120
Breaking strength[N/mm^2]	5	20	25
Bending strength [N/mm^2]	8	35	38
Thermal coefficient of expansion	11	13	13
Thermal conductivity [W/m K]	1	0.8	2
Damping coefficient	0.01	0.02	0.015
		100	100
Contraction [mm/m]	0.2	0.015	0.015
Slow yielding [mm/m]	0.8	–	–
Consolidate duration [days]	2.8	1	1 h
Dynamic viscosity [10^{-3}Ns/m^2]	100	30	0.1

Table 2

Mechanical characteristics of unsaturated polyester-resin NESTRAPOL 220 [4]

Characteristics	Resin	Resin + fiber glass %		
		30	**50**	**65**
Breaking strength [N/mm^2]	50	105	230	550
Specific elongation [%]	5	2	2.2	1.7
Bending strength [N/mm^2]	90	190	290	520
Shock strength [N/mm^2]	50	780	1050	1620
Compressing strength [N/mm^2]	165	240	305	500
Longitudinal elasticity modulus [N/mm^2]	3 900	8 000	10 100	2 700

The effect depends on the following factors:

- the type of reinforcement material selected;
- the manner of this disposal;
- the ratio of reinforcement material;
- adherence of reinforcement material with the plastic matrix.

The composite materials, reinforced with fiber glass are used the most, this being justified by the pretty low cost of fiber glass. They use many kinds of fiber glass, and the mechanical characteristics for four of these, are presented in Table 3.

Table 3

Mechanical characteristics of fiber glass used to reinforce the plastic materials [4]

Characteristics	Glass			
	E	**S**	**D**	**C**
Density, q [kg/m^3]	2 540	2 490	2 160	2 490
Breaking strength, R_m [N/mm^2]	3 515	4 675	2 500	2 815
Longitudinal elasticity modulus at 220C [N/mm^2]	73 815	87 000	52 000	70 300
Specific elongation at 220C [%]	4.8	5.4	4.7	–
Specific strength, R_m/q [s-2m2106]	1.38	1.88	1.15	1.13

Glass E is a calcium and aluminum borosilicate and has the largest utilization in industry. Glass S has the best characteristics at elevated temperatures and contains SiO_2(65%), Al_2O_3(25%), MgO(10%). Glass D has a good dielectric characteristic, and glass C has a good resistance at acids.

The die at the superior face is endowed with a holding down ring. This must have sufficient strength to withstand repeated impacts from the exploding charge, without forming.

Because concrete exhibits very low properties in tension, it is essential that tool design for explosive forming considers the nature of shock waves produced, to assure wave reflection in compressing. Tension forces produced by shock waves reflected of the encasement material can cause rapid deterioration of the die surface.

4. EXPLOSIVE FORMING

Sheet material is stainless steel 347-ASTM A 240, having the thickness of 3.18 mm and the diameter of 1 140 mm. Two pieces in torus form, with an outside diameter of 869 mm and an inside diameter of 419 mm, have been formed using as an explosive the HITEX-NH8 type. Each piece is formed in two shoots and after the first shoot heat treatment is made. Fig. 3 shows the die ready for underwater detonation, while Fig. 4 shows the piece drawn into forming die.

The method used in these experiences is the tank-forming underwater. The blank is clamped to the die with a vacuum-tight joint. A vacuum of approximately 6…8 mm Hg is then drawn in the cavity between the sheet and the die. After the vacuum has been drawn, the explosive charge is positioned at a carefully calculated distance from the work-piece. Next, the die and the charge assembly are lowered into the water tank and the charge is detonated. The die with the formed part is then removed from the water and the parts are taken out for inspection.

The operation must be performed with great care, by special and certificated staff, that know how to handle the explosive materials. The place in which the experiment is being made must be located at a certain distance of the

Fig. 3. Die ready for underwater explosion.

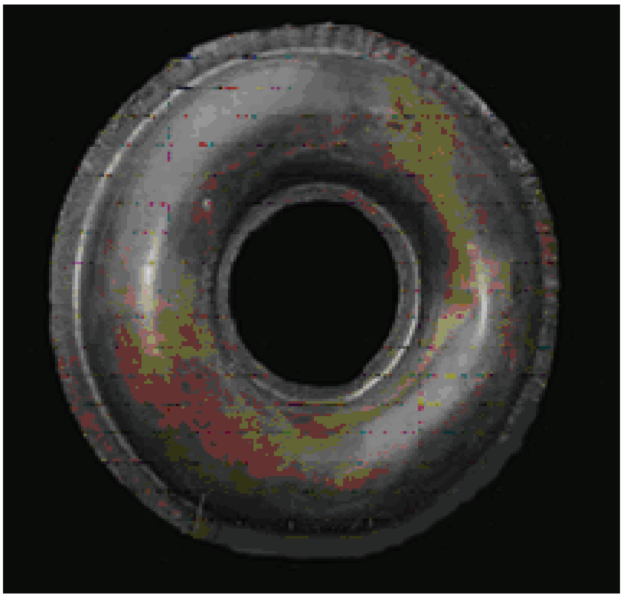

Fig. 4. Piece of stainless steel, drawn by explosive forming.

other buildings, and the staff must perform their activities in a special place, protected against the eventual solid residuals that may be detached during the detonation.

5. CONCLUSION

The purpose of this article is to show one example of metal-epoxy-concrete die construction for explosive forming of a complex piece. The technique used is to make a plaster master of the die-cavity, which is then coated with epoxy resin, reinforced with fiber glass. An adequate amount of reinforcement rodding and steel plates is placed in construction. The efficiency of this die has been verified by making two pieces of stainless steel.

Using the concrete, metal and epoxy die is an important advantage, first of all because the low costs of materials and of the raw materials, and second, because of the conversion cost substantially lower than that of standard dies. In the same time, the quality of the final parts is better compared to that of the parts obtained by some of the classical methods, derivated from the high-rate forming (75–180 m/s) and the plasticity characteristics of the metallic material constrained to deformation by shock.

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