CHAMBERS FOR EXPLOSION WELDING OF METALS (REVIEW)

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Existing protection equipment and explosion chambers for explosion treatment of metal are analysed. The focus is on metal chambers for explosion welding. Advantages and drawbacks of different designs of the chambers and prospects for their upgrading are outlined.

Keywords: *explosion welding, explosion chamber, tubular explosion chamber, explosive*

Explosion welding (EW) has been applied to advantage for about half a century in different industries. The volume of products manufactured by using this technology is growing every year. The range of products manufactured by EW is also continually growing. Reportedly, today in the world there are over 20 organisations working in the EW field, and more than 40 organisations applying other explosion technologies [1]. The continually growing demand causes increase in the need for the EW equipment.

The EW process can be performed in open grounds, for which the necessary conditions are availability of large sites and remoteness from inhabited localities. As this is inseparably linked with substantial costs of transportation and increase of production prices, the favoured variant is the use of workshop explosion areas. The adverse by-factors in EW are air shock waves, noise and pollution of the environment with toxic explosion products. Therefore, the efforts on development of various devices and explosion chambers for protection from the damaging factors of explosion were initiated simultaneously with the emergence of EW.

Different methods are employed to localise the damaging factors of explosion, the simplest being filling (tamping) the external explosive charges [2] with inert materials. Reduction of the intensity of shock waves in case of using tamping is caused by consumption of part of the energy of a charge for crushing and scattering of the tamping material. The key drawbacks of this method are increased pollution of the environment with the explosion products and need to make tamping for each explosive charge.

Water curtains can be used to reduce the intensity of shock waves. For example, Company «DMC Nitro Metal» (Sweden) uses a water curtain formed in air by spraying water with an additional low-capacity explosive charge blown up with some lead [3]. This method is less labour-consuming than tamping, but it has the same drawbacks.

The phenomenon of intensive damping of shock waves in foams [4], which are the 3–5 % water solution of a surface active material, was discovered in the course of work conducted by the E.O. Paton Electric Welding Institute in 1973. The foam absorbs toxic gases and dust particles, damps noises, but it does not solve the problem of decreasing seismic disturbances and protection from splinters.

Of interest are devices used to damp shock waves in mines. As to the method used to reduce the shock waves, they are subdivided into solid, perforated and disintegrating. Solid barriers damp the waves completely, whereas perforated and disintegrating — partially. The solid barriers include steel doors and concrete flat arches, which damp the waves due to their reflection from the arch faces and subsequent interaction of the resulting reflected waves [5]. The perforated barriers have holes and labyrinths for the air flow, the shock wave damping factor achieved in this case ranging from 1.1 to 2.9, depending on the perforation degree [6]. An example of the perforated barrier is a screen made from steel or hemp ropes with wooden posts or conveyer belt strips interweaved into it to raise the efficiency of damping of the shock waves.

Used mine works, mines, tunnels of other subsurface structures that served their time have found application for arrangement of sites for explosion treatment of metals. The advantage of such sites is that performing the work in them does not depend on the season, time of day or weather conditions. Temperature, humidity of air and its composition remain constant in a subsurface ground, which permits optimising the technology and producing items of the improved quality. Natural vaults of the subsurface ground protect the industrial and civil structures in the neighbourhood of the ground from the effects of the shock waves and reduce the level of noise pollution.

Despite the positive experience of using mine works for explosion treatment of metals, it should be noted that they are usually situated in the mining regions, rather than in the developed engineering regions. This causes difficulties related to transportation of raw stock, explosives and other required materials to large distances. Arrangement of subsurface grounds involves difficulties with shipments within the site and problems of the sufficient strength of the vaults. Another difficult problem is ventilation of the interior after explosion and prevention of increased humidity.

One of such grounds is situated in subsurface stone pits in the state of Pennsylvania (USA), and is employed by the DMC Company. The plates assembled for welding and put on a massive platform are fed to the explosion tunnel chamber by railway lines fitted with a reliable damper. After explosion and purging, the platform with a clad piece is rolled out from the tunnel chamber [7].

Building of the explosion chambers and equipment allowed the metal treatment processes to be performed in a workshop. Initially, the attempts were made to build concrete explosion chambers. They remained intact somewhere and are still in operation. Such chambers are cumbersome and look like a thick-walled round building with a dome-shaped roof. Construction of such a chamber requires high material costs, while the permissible value of an explosive charge is low [7]. Therefore, now the concrete chambers are abandoned, and metal explosion chambers are built instead. The latter can be located both in grounds and in workshops.

Despite a wide variety of the above protection means, the metal explosion chambers are the best choice for mass production of small-size items.

One of the first Ukrainian explosion chambers was a vacuum chamber fabricated and employed at the Kharkov Aviation Institute [8]. The chamber was intended for sheet-metal forming by using charges with up to 2 kg of explosive. Physically, it had the form of a cylindrical shell with a 3 m diameter and 2.5 m high cap and a support, on which it was possible to mount a mandrel with a diameter of up to 2 m. The chamber had no loading hatch, and access to the mandrel was provided by removing the shell with the help of a telpher.

At present, explosion forming is carried out by using different types of the explosion equipment. Each type of the equipment has its own technological peculiarities, advantages and drawbacks, which depend on the operations performed (drawing, expansion, sizing). The work performed by the Kharkov Aviation Institute, generalisation of the experience accumulated by the CIS factories that apply explosion treatment of metals, and analysis of potentialities of each type of the equipment as to dimensions of workpieces, power consumption, service properties, classes of workpieces, price and productivity made it possible to work out requirements [9] to all types of the equipment:

- operating reliability, strength and durability;
- minimal capital expenditures for their construction;
- possibility of using them to form pieces with a wide variety of dimensions;
- convenience and simplicity in operation.

Main types of the hydraulic explosion equipment include hydraulic explosion pools, armour pits, armour chambers and vacuum chambers. The pools are the basic equipment for hydraulic explosion treatment. They are meant for accommodation of a transmitting medium (water) and performance of an explosion safe for the attending personnel. The pool is a steel cylindrical or conical water-filled shell, which is strengthened by reinforced concrete. The die with a billet and an explosive charge fixed on it is placed at the centre of the pool on a bottom steel plate resting on a concrete anvil block. The anvil block and walls of the pool are insulated by a hydraulic seal located between them.

As proved by practice, the armour pits with concrete walls have short service life, as concrete quickly crumbles out under the explosion load effect. Sometimes the use is made of the structures wherein the armour pit walls are made from concrete protected by metal plates from the effect of the shock waves. Wooden armour pit have walls made in the form of two cribs of logs with a diameter of 15–20 cm. In operation, the armour pits should be carefully ventilated from gaseous explosion products [7].

A large scope of theoretical and experimental works on strength design and calculation of shells, hatches, supports and other facilities was completed by the Technological Design Institute of Hydro-Pulse Techniques of RAS SB (KTI GIT) [10]. Explosion chamber KVG-16 for treatment of extended pieces has a horizontal cylindrical shell (1.6 m diameter, 0.09 m thick and 8 m long) designed for blowing up of a charge with a capacity of up to 16 kg of explosive (Figure 1). The chamber has a hatch with two lids, i.e. the internal (load-bearing) lid that takes up the main load during explosion, and the external (sealing) lid. The chamber houses a work table (support) made from metal plates with rubber gaskets, the important drawback of which is a short service life of the upper plate that withstands a limited number of explosions. The special manipulator is used to load the chamber.

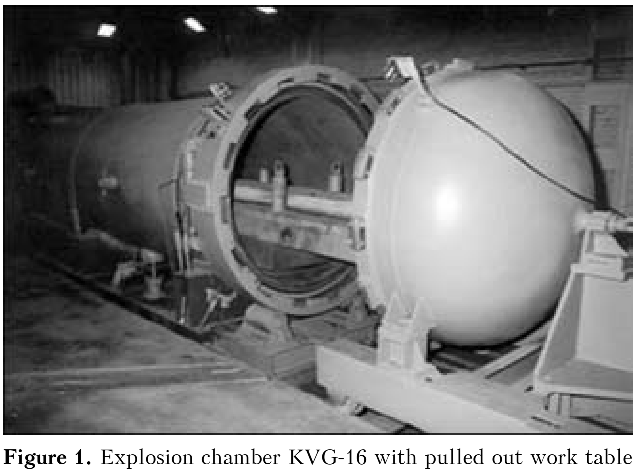

Figure 1. Explosion chamber KVG-16 with pulled out work table

It pushes a workpiece with the charge into the explosion chamber. The external lid is opened by using a hydraulic cylinder, and the internal one is opened and closed by the manipulator rod. The chamber is fitted with an emergency hatch. Such chambers are applied at the Novosibirsk Switch Factory.

Semi-automatic chamber VK-10 made on the basis of the experience accumulated by Scientific Production Association «ANITIM» (Barnaul, RF) can serve as an example of the modern spherical explosion chamber for explosion treatment of metal (Figure 2) [11]. The chamber 280 t in weight is designed for 20 kg of explosive. The chamber is 10.5 m in diameter, and its casing wall thickness is 20 mm.

Unique chamber 13YaZ mounted on a special foundation (Figure 3) is a high-capacity spherical explosion chamber. It functions at the Moscow Regional Shared-Use Explosion Center of the Russian Academy of Sciences (SUEC) [12]. The chamber is an ideal sphere 12 m in diameter (the difference in diameters at several points is no more than 3 mm). The casing of the chamber is made from armour steel 100 mm thick. Its weight is about 500 t, and weight of its foundation is 320 t. The chamber has two loading hatches, i.e. the top one with a diameter of 600 mm, and the bottom one with a diameter of 800 mm. It is designed for blowing up of 1000 kg of explosive, and it successfully passed the tests. However, the chamber is intended for research purposes to study explosions in fuel gas mixtures and is of little use for industrial purposes.

Some chambers have structures with multilayer shells. For instance, a two-layer cylindrical chamber with a capacity of 110 m^3, consisting of two metal cylinders with a wall thickness of 50 mm, the 350 mm thick gap between which is filled up with steel shot, is in operation at SUEC. The chamber is designed for blowing up of 50 kg of explosive.

The chamber intended for explosion welding of pipes is characterised by the special loading and sealing methods [13]. The ends of its horizontal cylindrical shell have coaxial holes for loading of the pipes to be welded and explosive charges inside it. The gap between the pipes and shell is sealed with a water curtain.

Explosion protection chambers (anti-diversionary units) have found acceptance along with the conventional explosion chambers of the research and industrial application. As a rule, these chambers are of a rectangular shape, can operate in the standby mode, and are not re-used after blowing up of a limiting weight of explosive [10]. Such chambers are unsuitable for explosion treatment of metal.

In the 1970s, the E.O. Paton Electric Welding Institute developed a fundamentally new design of a high-capacity explosion chamber designed for the explosive charges of up to 200 kg. The casing of the chamber is made from fragments of tubes plugged from the outside, the axes of which intersect at the chamber centre. Strength and high lag effect of the tubular casing are provided by the presence of a sufficient number of rigid connections between the tubes, and by filling the inter-tube space with sand. The main advantages of this structure are a high technological effectiveness, thus allowing it to be manufactured from mass-produced gas distribution tubes, and repairability.

Figure 2. Semi-automatic explosion chamber VK-10

Two high-capacity (for 200 kg of explosive) tubular explosion chambers (TEC) were built. The first was made at Research and Engineering Centre «Explosion Treatment of Materials» of the E.O. Paton Electric Welding Institute (Glevakha, Kiev Region) (Figure 4), and the second — at Design Bureau «Yuzhnoye» (Dnepropetrovsk).

The drawback of the TEC design is a long time of operations of loading and unloading of billets, which makes these units insufficiently effective for commercial application. In this connection, in 2009–2010 Research and Engineering Centre «Explosion Treatment of Materials» developed and mounted TEC with a semi-automatic mechanism for feeding and unloading of billets (Figure 5). This chamber is an upgraded scaled (1:5) model of TEC and designed for blowing

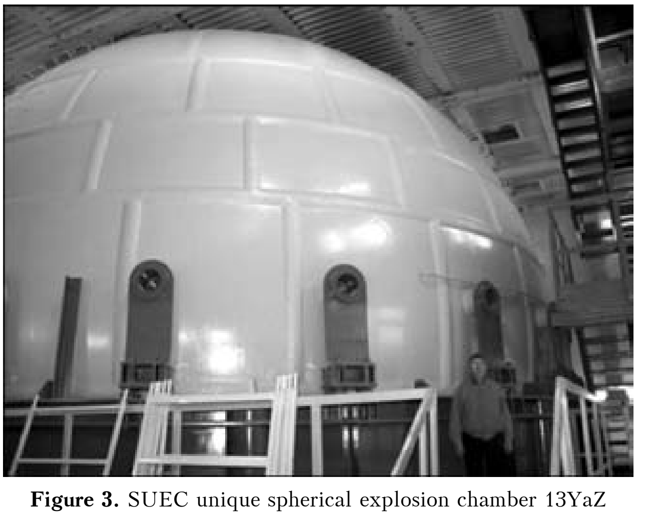

Figure 3. SUEC unique spherical explosion chamber 13YaZ

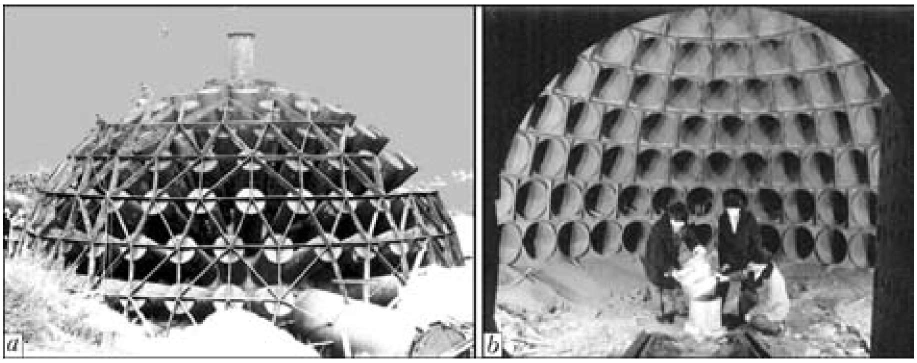

Figure 4. Tubular explosion chamber for 200 kg of explosive (Glevakha): *a* — view during construction; *b* — inside view

up of up to 2.4 kg of explosive. According to the principle of scale modelling, the M 1:5 chamber corresponds to a chamber for 300 kg of explosive in M 1:1.

The scaled model of TEC is a three-stage welded structure with an inside diameter of 2 m. The main (middle) stage consists of 283 sections of steel tubes with a diameter of 140 mm, length of 600 mm and wall thickness of 4.5 mm. The external stage is composed of bottoms 8 mm thick, plugging tubes and steel braces with a diameter of 16 mm, which connect tubes to each other (so-called «bundles», looking like handsets). The internal stage consists of the hemispheric sectors 8 mm thick, which connect inlets of the tubes and form a perforated internal hemispheric shell. Weight of the chamber casing is 3.6 t. Therefore, the ratio of the metal weight in tons to the permissible weight of explosive in kilograms is 1.5.

Now the phase of development of a general-application explosion chamber can be considered completed. The main types of such chambers (spherical, cylindrical, tubular) and peculiarities of gas-dynamic processes and dynamics of structures in them have been identified, this providing the scientific basis for design engineering [10]. What is lacking for completeness is statistics of damages and failures, which would allow formulating the procedure for evaluation of reliability and durability of an explosion chamber under the regular operation conditions. The first attempt to develop such a procedure was made in study [11]. However, it is based on the statistical data generated from operation of welded structures, and not from tests of the explosion chambers.

Figure 5. General view of semi-automatic tubular explosion chamber

The next phase of development is to build single-purpose explosion chambers as an element of equipment for large-scale manufacture of standard products (in explosion forming this phase began already in the last century). The following problems will remain topical for single-purpose chambers:

- improvement of systems for automatic loading and unloading of billets and ventilation of the interior of an explosion chamber to reduce the time interval between explosions; and
- lowering of the level of noise and seismic effect.

One of the specific features of explosion welding in chambers is the use of flat explosive charges, the size of which is commensurable with the size of an explosion chamber. This excludes the possibility of using of the spot charge and spherical/cylindrical symmetry simplifications, which are very convenient for theoretical analysis. It is well-known that a spherical explosion chamber should have a minimal weight for the specified weight of a maximum permissible explosive charge. For cylindrical symmetry this indicator is a bit higher. And for large flat charges it grows several times [10], which was also proved by our measurements in the chamber. Therefore, an explosion chamber for explosion welding should have specific design peculiarities that make it different from conventional chambers. The problem of designing of such chambers is far from being solved as yet.

Another peculiarity is the use of explosives with inert fillers (sand, most often). This allows reducing the weight of an explosive and level of noise, but hampers ventilation of the interior of the chamber and increases emission of environmentally harmful impurities into the atmosphere.

Finally, explosion welding is characterised by increased requirements to a material and design of the support. It should feature a good absorption of dynamic impact energy and have an ability of being deformed uniformly, as much as possible, over the entire surface area to minimise residual distortions of large-size flat pieces. At present, metal shot is considered to be the best material for supports. It provides a lower level of residual distortions compared to other materials. However, further decrease of residual distortions is still a topical problem.

Another pressing problem is the possibility of evacuation of explosion chambers. It is reported that evacuation improves the quality of explosion welded joints. At the same time, it makes design of the explosion chambers more complicated and more expensive, and reduces their productivity.

In the future, application of special workshop automated explosion chambers will lead to increase in output of thin-sheet bimetal for its subsequent utilisation to manufacture elements of machines and devices, as well as bimetal of any combination and thickness, including for further rolling.

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From the history of welding

TO 130th ANNIVERSARY OF THE FIRST METHOD OF ARC ELECTRIC WELDING

In 1881 the electrical engineers, who came to Paris to attend the International Electrical Engineering Exhibition, watched Nikolas de Benardos, colleague of P.N. Yablochkov, the famous inventor of «Russian light», performing brazing-welding of different exponents by heating parts using electric arc in the laboratory of N.I. Kabat. In a facsimile list Benardos noted that projects and inventions from Nos. 21 to 39 (1877–1881) were made in St. Petersburg; 40 to 42 — in Zakaspijsky region, where the company of Yablochkov implemented the electricity, and 48 to 54 — in Paris. No.46 stated «Electric brazing of metals, electrogefest». The considerable part of this list contains inventions in the field of electric engineering: corrugated batteries, electric arc lamp, candlestick for the candle of Yablochkov with automatic switch of a current, battery of powder of crystal lead, commutator for filament lamps, etc.

The life and activity of the inventor of the first method of a new type of joints attracted attention after 50 years when the arc welding turned into the leading technology of manufacturing the critical metal structures due to efforts of many invertors, scientists, rationalizers.

Nikolay N. Benardos was born in July 26 (August 7), 1842, in the village Benardosovka (now village Mostovoe of Bratsk district of Nikolaev region, Ukraine) in the family, coming of military servants of Greek origin.

Being a child he learned at home in Benardosovka. He learned not only reading, writing and different languages, but also forgery and joinery at the splendid grandfather's workshop. He entered medical faculty of Kiev University, then he was transferred to Moscow Petrovsko-Razumovskaya Agricultural Academy.

In 1869 he left to register his mother's heritage (a land in 12 km from town Lukh of Kostroma province, Russia) and stayed there. He built a house, workshops, greenhouse, also helped in building school and drug-