Manufacturing technology stamp-welded workpieces based on porous-net material with desired properties

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Abstract

The manufacture of stamp-welded and porous elements of porous-net material (PNM) from stainless steel 12H18N10T (0.12% C, 18% Cr, 10% Ni, 1% Ti) is difficult due to the low ductility under tension and the lack of weldability. It limits the use of PNM, although the fact that they may have the necessary technological and operational properties. The effect of porosity and heat conductivity anisotropy on the strength of welded splices of parts made of PNM have been established. Technologies of electron-beam welding (EBW) and sheet stamping of filter elements, which are implemented during the manufacture of prototypes of filter elements with a cleaning precision 10-12 microns, are presented.

Introduction

For the implementation of different technological processes, it is necessary to create new equipment, which includes hydraulic and pneumatic systems. To ensure the required service life of such installations it is necessary to use reliable filter elements. Thus, the creation of reliable filter elements is an important task of modern engineering.

In a number of sources [1, 2], it has been shown that for efficient refrigeration of the walls of power plants caused by temperature increase and velocities of energy carriers increase, a method of gas supply to the boundary layer through a porous shell is used. Also, for increase of modern pneumatic and hydraulic systems reliability, the requirements for purity of the liquids and gases used in them are increased due to their filtration. In the process of creating a design of filters, an important step is an informed choice of permeable elements [3, 4], which should provide the necessary cleaning precision, energy carrier consumption, withstand the required pressure and temperature, and also have the necessary corrosion resistance [5].

Reliable operation of such structures largely depends on the right choice of parameters for the properties of materials (PM). To PM include a fabric of man-made and natural fibers [6], the grid of metal wires, blanks, obtained from metal powders [3, 4, 7] and fibers, perforated sheets [8] and some others.

As a result of the analysis of the electric power plant structures and their working conditions, it was revealed that the most forward-looking are porous materials on a metal base. Woven nettings made from corrosion-resistant steels have been used as blanks for filter elements. The cleaning precision of liquids and gases by one layer of the mesh reaches 20...40 microns [3], some improvement of filter characteristics can be achieved using multilayer briquettes of grids.
The creation of permeable materials based on metal fibers (metal matrix composites - MMC) is interestingly, studies [9, 10, 11] show that these materials have excellent hydraulic and mechanical properties. However, the lack of data about the stampability and weldability of fiber materials does not currently allow recommending it for the manufacture of stamped workpieces with specified properties.

Experimental researches of hydraulic, filtering, mechanical and technological properties of powder porous materials (PPM) from corrosion-resistant steels have shown that the main advantage of this type of permeable blanks is the ability to retain mechanical particles size up to 2 microns by filtering liquids and gases [3, 7]. An important factor limiting the use of PPM for the manufacture of permeable workpieces is bad stampability because the elongation of these materials on fracture under tensile stress does not exceed 1.5%. Made experiments with the EBW of the PPM blanks on standard equipment showed the possibility of synthesis full-strength joints. However, as a result of the uneven structure characteristic of highly-porous PPM, in the abutting joints in the areas with a large pore size, burn-through occurs. For obtaining high-quality seams in the manufacturing of workpieces made from PPM grade H18N15 (0.08% C, 18% Cr, 15% Ni,), work [12] proposed to use the remaining slices made of stainless steel 12H18N10T (0.12% C, 18% Cr, 10% Ni, 1% Ti), the fusing temperature of which is lower than the fusing temperature of the welded blanks.

The analysis of the structures, manufacturing techniques and service conditions of elements for the cleaning of mechanical pollution of liquids and gases [3, 4, 12], thermal protection systems of rocket engines [3, 13], cases of turbine blades for combined cycle gas turbine [14, 15, 16] and gas turbine engines [1, 17, 18], capillary intakes [9], etc. has shown that porous-net materials (PNM) made from steel grade 12H18N10T (0.12% C, 18% Cr, 10% Ni, 1% Ti) have optimal properties. PNM are made by hot reducing in vacuum-processed woven mesh briquette. These materials provide the specified performance characteristics and have high mechanical [19, 20, 21] and technological properties [22], which allows to manufacture a stamped-welded structures with specified properties and the required configuration.

The existing results of theoretical and experimental researches in the area of pressure welding and hot reducing of multilayer sheets [23, 24, 25] were used to create sheet porous-net materials.

**Research methodology**

Due to the pronounced anisotropy of the PNM properties, the ratio of effective thermal conductivity of edges in the thickness $\lambda_\perp$ and in the direction perpendicular to the movement of the welding source $\lambda_w$ has a significant impact on the seam appearance during fusion welding processes. During the welding of blanks, which are characterized by low thermal conductivity in thickness (for example, highly-porous), depending on the value of $\lambda_w$, the origination of defects of the following types is possible:

a) split of the seam during the process of crystallization - typical for blanks with a high value of $\lambda_w$ as a result of intensive heat removing in the flat surface of sheet the fusion penetration decreases and the temperature gradient across the width of the molten crater increases;

b) incomplete fusion of individual wires in the arrises of the connectable elements with the metal seam - occurs for blanks with a low value of $\lambda_w$.

Such defects are experienced from the action of surface tension forces at the interface of the liquid metal of the melted on the surface wires and the molten crater.

Experiments have shown that for blanks with high anisotropy of thermal conductivity in the sheet plane, the width of the impermeable zone (seam) does not depend on the direction of welding, but increases with a decrease of thermal conductivity in the direction of the thickness of the arrises being welded [23].

The study of weldability of PNM from steel grade 12H18N10T (0.12% C, 18% Cr, 10% Ni, 1% Ti) has shown that with decrease in porosity and increase in ratio $\lambda_\perp / \lambda_w$ the quality of welded joints increases. For the manufacture of highly-porous welded structures, it is efficient to use PNM with a
smaller amount of thermal conductivity anisotropy in the plane of the sheet, for example, based on grids with squarely cells at an angle of 45°.

The rational values of the EBM conditions of abutting joint are determined by using the theory of similarity and the regression analysis method. Using the obtained equations and a criteria-based correspondences for the calculation of rate of energy input in welding stainless steel grade 12H18N10T (0,12% C, 18% Cr, 10% Ni, 1% Ti), an equation is obtained for the approximate calculation of the energy required for the origination of abutting joint in EBW:

\[
\frac{q}{V_w} = 20 \cdot h_b \cdot T_f \cdot (1 - P) \cdot \sqrt{h_{\perp}} \cdot C_m \cdot \rho_m \quad (1)
\]

where \(q\) – is the effective power of the welding source; \(T_f\) – fusing temperature of the material; \(V_w\) – welding speed; \(\rho_m\) – is the density of a compact material; \(C_m\) – is the heat capacity of the compact material 12H18N10T (0,12% C, 18% Cr, 10% Ni, 1% Ti); \(h_b\) – is the thickness of the PNM blanks.

The study of the mechanical properties of welded joints PNM in the conditions of uniaxial and biaxial tensions made it possible to reveal that with an increase in the porosity of the base material, the weldment efficiency of the welded joint decreases, the value of which with porosity \(P > 0,2\) can be described by the following empirical correspondence:

\[
\frac{\sigma_w}{\sigma_{B_{x,y}}} = 1,3 - 1,5 \cdot P. \quad (2)
\]

In expression (2), \(\sigma_{B_{x,y}}\) – is the ultimate stress limit of the PNM under uniaxial tension in the direction of the wire grids; \(\sigma_w\) – seal strength of an abutting joint with the same porosity in the direction of the wire grids.

Using expression (2), we can formulate the following requirement, limiting the amount of porosity of welded blanks:

\[
P = 0,67 \cdot \left[1,3 - \frac{\sigma_w}{\sigma_{B_{x,y}}} \right]. \quad (3)
\]

EBW is the optimal type of welding of porous blanks when creating filtering elements for precision cleaning of liquids and gases from mechanical pollutions. For the development of welding technology and study of the seal strength of welded joints, studies have been carried out where the current of the beam, the welding speed and the porosity of the blanks were varied. The intervals of variation this parameters given in Table 1 were determined due to the analysis of expression (1). The value of the relative durability of welded joints \(\frac{\sigma_w}{\sigma_{B_{x,y}}}\) was taken as an example of the optimization parameter.

| Parameter         | Layers | Intervals of variation | Dimensionality |
|-------------------|--------|------------------------|----------------|
| Beam current      | lowest-1 | zero0 | highest+1 | 10 | mA |
| Welding speed     | lowest-1 | zero0 | highest+1 | 15 | m/h |
| Porosity          | lowest-1 | zero0 | highest+1 | 0,1 | –   |
During the welding process, the focal spot diameter \( d_s \), focal length \( l_0 \) and accelerating voltage \( V_v \) were not changed and maintained, respectively. \( d_s = 0.5 \text{mm}, l_0 = 120 \text{mm}, V_v = 30 \text{kV} \). The value of \( \sigma_{B_{x,y}} \) for PNM with 0.35 and 0.15 porosity was 190 and 300 MPa, respectively. As a computational model, a first degree polynomial was defined, the coefficients calculation of which allowed to obtain the following regressional equation:

\[
\frac{\sigma_w}{\sigma_{B_{x,y}}} = 0.804 + 0.075 \cdot P - 0.023 \cdot P \cdot V_w + 0.0057 \cdot V_w^2.
\]  

(4)

The manufacture of filter elements was carried out by sheet stamping of PNM in the following sequence (Fig. 1): manufacturing the round blank (a), molding the central part (b), rolling-out (c), percussion and bead forming (d).

![Figure 1. The sequence of sheet stamping operations of filter element](image)

The diameter of the blank required for the sheet stamping manufacture of filter elements can be defined as:

\[
D_b = \sqrt{\frac{d_s^2 \cdot (\sin \alpha_{ch} - 1) + d_h^2}{\sin \alpha_{ch}}} + 4 \cdot b_{ch} \cdot (d_B + b_{ch}).
\]  

(5)

The value of blank elongation during rolling-out of the bell conical section of the shell is defined as:

\[
ed = \frac{d_B - d_n + \sin \alpha_{ch} \cdot (2 \cdot b_{ch} - 1)}{(1 - P) \cdot (D_h - d_n) \cdot \sin \alpha_{ch} + P(d_B - d_n + 2 \cdot b_{ch} \cdot \sin \alpha_{ch})}.
\]  

(6)

In formulas (5) and (6) \( d_B, d_n, b_{ch}, \alpha_{ch} \) are the dimensions of the filter element shown in Figure 1.

The study of the influence of sheet stamping operations on the change in pore size has shown that during the process of rolling out the conical section of the filter element, an increase in the pore size
was practically not observed, since with \( d_n = 15 \text{mm}, d_y = 50 \pm 2 \text{mm}, h_{ch} = 5 \pm 2 \text{mm}, \alpha_{ch} = 75 \pm 5^\circ \) stretch value was \( e_s = 0,04 \ldots 0,05 \) (stretching degree \( k_s = 1,06 \)). In the process of forming the cup as a result of biaxial stretching, the average size increases by 24%, but since this section is short, this increase does not have a significant effect on the maximum filtered substance consumption through the filter element.

The magnitude of the elongation at the arises of the porous blanks during bead forming the internal diameter of the filter element can be approximately defined as:

\[
e_l = \frac{2 \cdot h_{ch}}{(\pi \cdot d_n - 2 \cdot h_{ch})},
\]

\( h_{ch} \) - the height of the spout diameter \( d_n \) (Figure 1).

The analysis of formulas (6) and (7) has allowed to establish that \( e_l > e_s \), therefore, in the creating the production process of manufacturing PNM for a filter, the following condition should be envisaged:

\[
\delta > e_l
\]

\( \delta \) – is the breaking elongation.

The flow-process chart for the manufacture of a filter intends the performance of ring seams during welding of individual elements. In this case, the quality of welded joints is determined, most commonly, by magnitude of the filter elements porosity.

**Research results and discussion**

The carried out studies of the weldability of PNM and the developed EBW technology for porous blanks were used in the design and manufacturing of stamped-welded filter elements with cleaning precision of 10...12 μm, the sketch of which is shown in Fig. 2:

![Figure 2. Sketch of the filter, providing the cleaning precision 10 ... 12 microns: 1 - axis; 2 - filter elements; 3 - bushings.](image-url)
The technological process of filters manufacturing includes EBW of porous elements with an axis, bushings among themselves. Filter elements were made by sheet stamping PNM thickness of 0.5 mm and P = 0.45, obtained by rolling 13 grids with square cells, the size of which was a = 0.04 mm, located at an angle of 45°. After ultrasonic cleaning in freon gas, porous blanks were set up in special devices guaranteeing the assembly of the welded elements and their rotation.

Welding was carried out on a current of 5...6 mA with an accelerating voltage of 50 kV with a focal spot diameter of 1 mm. The welding speed was at the connection of the filter elements with the axis and bushings of 6.3 m/h, and among themselves - 22 m/h. Quality control of the welded joints of the filter under hydrostatic test conditions has shown that the probability of obtaining a defect-free welded joint is 0.96.

Analysis of equations (5), (6) and (7) has allowed to establish for obtaining the filter elements with following dimensions: d_n = 15 mm, d_p = 50 mm, b_ch = 5 mm, h_ch = 2.5 mm, a_ch = 75 ± 5°, blank diameter for sheet stamping is 62 mm, the elongation during the rolling-out process of the conical part of the porous element is e_s = 0.04, and during the bead forming, e_l = 0.118. As a result of significant deformations (e_l ≈ δ) on the arris of the spout, the cracks forming is possible. To eliminate possible defects, the shape of the abutting joints of element filters with the axis and filter bushings (Fig. 2) is designed in the way that the spout melts during the EBW process.

Analysis of equation (4) showed that with a porosity of the base material less than 0.25, an increase of weldment efficiency can be achieved by increasing of the welding speed, and with a porosity of more than 0.25, a decrease of welding speed results to an increase of σ_w/σ_{B_{x,y}}. In this case, the beam current, equal to 0.45...0.65 mA, slightly has an effect on the joint efficiency.

Metallographical researches revealed the undercuts in areas where the wires did not melt with the seam metal, the number of which was increasing with increasing the porosity. The width of the obtained seams on prototypes with a thickness of 2.8...3.8 mm did not change significantly with the variation of welding mode parameters and was 2.5...3.0 mm.

The study of the influence of the welding cycle on the change in the hydraulic and structural characteristics of porous blanks has shown that the decrease of the permeability of welded joints is proportional to the arris area, while the pore sizes in the weld zone do not change.

In the manufacturing of welded structures, the requirement of manufacturability should be taken into account, which is guaranteed by the rational choice of the blank material, the shape of the welded elements, the type of welding and measures to improve the quality of workpieces. To obtain welded structures with high capacity of work, should tend to use PNM with a lower porosity and minimal anisotropy of properties in the flat surface of sheet.

In the case when it is necessary to obtain workpieces from highly porous materials, an improvement in the quality of welded joints can be achieved by increasing the thermal conductivity in the direction of the thickness of the welded arrises, and if possible, by using diffusion welding.

The results of the researches used in the design and manufacture of stamped-welded filters with a cleaning precision of 10-12 microns.

**Conclusion**

The strength of the seal joints obtained by the EBW is determined by the chemical composition, the shape of the welded elements, the anisotropy of the thermal conductivity and the porosity of the welded edges arrises. With an increase of the ratio of the effective thermal conductivity coefficients in the thickness λ_⊥ and in the direction perpendicular to the movement of the welding source λ_w and a decrease of the porosity of the arrises, the quality of the welded joints increases.

The manufacturing technology of the filter element by sheet stamping is carried out in the following sequence: manufacturing the round blank, molding the central part, rolling-out, percussion and bead forming. It was established that the value of the workpiece elongation when the conical
section of the shell during the rolling-out depends on the geometric parameters of the filter element and its porosity.

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