Repair of radiator leaks by cold spraying

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Abstract. The possibility of sealing various parts through holes by cold spraying is considered. A method is proposed and calculation formulas are presented for determining the critical size of the hole that can be sealed in this way without the use of additional parts. The brand of the powder and the technological parameters of the process that allow the sealing of holes of the largest size are determined.

1. Introduction

Improving the technical and economic performance of products by obtaining functional coatings on the surfaces of machine parts is becoming more and more urgent every year. Cold spraying (CS) is a method that allows to obtain functional coatings, as well as to make up for lost volumes of metal during the repair of machine parts for various purposes [1, 2]. This method is successfully used, among other things, in the repair of cooling radiators of various systems of automotive equipment.

Modern motor vehicles, cleaning, construction equipment and energy equipment used both in agriculture and in other industries have several cooling radiators, both liquids and gases: the radiator of the internal combustion engine cooling system, the oil cooler of the engine, the radiator of the hydraulic system cooling, the oil cooler of the automatic transmission, the radiator of the interior heating stove, the air conditioner evaporator, the air conditioner condenser, the intercooler radiator.

These radiators can operate in a wide range of temperatures: from −35 °C to 125 °C. Radiators are exposed to various contaminants such as dust, dirt, and lubricants. When moving vehicles, radiators experience vibration loads, and can also receive mechanical damage when metal parts and stones get into them. Despite this, the radiator must provide the required heat removal. Radiators used in automotive equipment can be classified according to the material of manufacture, design, location of tanks and the shape of the tubes (Figure 1) [3-5].
Regardless of the design and material of manufacture, radiators are subject to defects, which are divided into mechanical and chemical damage.

Mechanical damage to radiators includes: leaks in the pipes and where they connect to the tanks; mechanical damage to the cooling tape and plates (dents, breakage of the cooling tape at the joints with the pipes, bends, crumples, local displacement of the plates, bends of the outer edges of the cooling plates); plugging of the radiator tubes due to contamination or during their repair (restoration of tightness).

Chemical damage to radiators occurs due to their interaction with the external environment, these include: corrosion of pipes, plates, belts and tanks [3-5].

Repair of the listed malfunctions is carried out by: soldering the cooling tape and leaks in the radiator tubes with solders; gluing the cooling tape and sealing the leaks of the radiator tubes with two-component adhesives; sealing the leaks by adding a sealant to the coolant; welding with a non-consumable tungsten electrode in an inert protective gas (argon) of cracks in the tanks and radiator tubes; plugging the radiator tubes in the places of its leaks with soldering, while the proportion of plugged tubes should not exceed 5%; cold spraying [3, 4].

A great competitive advantage of CS in comparison with other methods of spraying metal powders is that the air supplied at a pressure of 0.5...1.0 MPa is used as a transporting and heating gas, with a flow rate of 0.5 m³ / min, and the power required for heating it is 3...5 kW [2, 6-18]. For example, the installation "Dimet-402" has a mass of only 14 kg, air pressure up to 1.0 MPa with a flow rate of 0.3 m³ / min, which allows you to use this equipment in the field as part of mobile repair teams.

Cold spraying is used not only for sealing leaks, but also for filling up the lost metal volumes of other parts, including body parts, as well as for repairing castings.
When eliminating such problems, it is important to determine what the maximum diameter of the hole can be sealed by this method without the use of additional parts, for which the following process model was proposed.

Based on the fact that with CS, the sprayer can be tilted as close as possible to the surface of the part, then the walls of the hole in it can be considered as the spraying planes.

In this connection, the **purpose of the study** is to determine the maximum size of the hole of the $D_{cp}$ that can be filled with this method knowing the thickness of the part.

To do this, you need to determine the maximum height $h$ that can be increased on a single site with this powder (the maximum height of the applied layer), knowing which you can determine the maximum size of the hole $D_{cp}$, based on the calculation that this layer of coating will be applied along the entire perimeter of the hole (Figure 2).

![Figure 2](image)

**Figure 2.** Scheme explaining the model of hole sealing by the CS method: a) design scheme, b) for a round hole; c) for an oblong hole; d) a hole that cannot be completely filled.

Thus, the hole between the opposite edges of which the distance is less than $D_{cp}=2h$ (Figure 2. b and c), it is possible to seal it with the CS method, if the distance is greater in one of the directions (Figure 2. d), such a hole cannot be completely sealed without installing linings or additional "patches" (not the shaded area in the figure).

2. **Materials and methods of research**

The rod of the electrode E46-MR-3 ARS-3-UD GOST 9466-75, the State Standard 9467-75, the diameter of the electrode is 3 mm, was used as a single platform for spraying. The ends of the samples were aligned to obtain a plane perpendicular to the axis. Spraying was carried out on the Dimet-405 unit at an air pressure of 0.6 MPa, at different temperature conditions, but at the same powder consumption (1.0 g/s) [19-20]. Powders of the following grades were used for spraying: C-01-01, A-20-11, A-80-13, N-3-00-02 [20]. After spraying, cones were obtained, the height of the obtained cones was measured with a Brinell magnifying glass. The samples were weighed before and after spraying on a Sartorius 1201 MP2 scale with a measurement accuracy of up to 0.0001 g.

3. **Results and discussion**

Figure 3 shows the heights of the obtained cones for the studied powder grades. For powders of grades A-20-11, A-80-13 and N3-00-02, the height of the resulting cone did not depend on the deposition mode. The view of the obtained cones is shown in Fig. 4. At the same time, when the powder N3-00-02 was sprayed, the coating was peeled off, at low temperature conditions and only at the 5 temperature mode of spraying, the coating was not peeled off. When spraying the powder of the C-01-11 brand, the dependence of the height of the coating cone on the temperature regime was obtained (Figure 5). At the same time, the cone increased in width, relative to the initial diameter of the sample from 3 mm to 3.3 mm at the 4 temperature mode of deposition (Figure 4 b).
Figure 3. The height of the cone \( h \) obtained by spraying the studied powders.

Figure 4. Example of the resulting cones.

Figure 5. The dependence of the deposition height on the temperature for powder grade C-01-01.

Each of the sprayed powders is characterized by a certain angle at the base of the cone \( \beta \). You can determine this angle by using the diagram shown in Figure 6. From the presented diagram, the "sputtering" angle \( \beta \) is the angle between the legs of the right triangles \( \triangle ABH \) and \( \triangle AHC \). The triangle \( \triangle ABC \) is isosceles, and the height \( AH \) (\( h \)) divides the base \( BC \) (\( \delta \)) in half, hence \( BH = CH = \delta / 2 \).

Figure 6. Calculation scheme for determining the deposition angle \( \beta \) (a) and the deposition angle \( \beta \) for the studied powders (b).
Hypotenuse $ABH$:

$$l^2 = h^2 + \left(\frac{\delta}{2}\right)^2$$  \hspace{1cm} (1)

Knowing the sides of a right triangle, we find the angle $\beta$:

$$\cos \beta = \frac{2}{l}, \quad \beta = \cos^{-1}\frac{2}{l}$$  \hspace{1cm} (2)

To determine the critical size of the hole $D_{кр}$, which can be dusted, it is necessary to find $h$, with a known thickness of the part $\delta$ and the angle of deposition of the powder $\beta$. The found deposition angles for the studied powders are shown in Figure. 6 b.

For powder C-01-01, the deposition angle also depends on the deposition temperature, the dependence of the deposition angle on the temperature is shown in Table 1.

| Temperature range |
|-------------------|
| Mode | Temperature, °C | Powder deposition angle $\beta$, ° |
|------|-----------------|-----------------------------------|
| 2    | 300             | 47,7                              |
| 3    | 400             | 55,7                              |
| 4    | 500             | 66,0                              |
| 5    | 600             | 57,5                              |

In order to find the height $h$ at a known deposition angle $\beta$ we use the trigonometric function:

$$h = l \cos \alpha = l \sin \beta$$  \hspace{1cm} (3)

Hence the hypotenuse:

$$l = \frac{2}{\cos \beta}$$  \hspace{1cm} (4)

Substituting the resulting expression in (3), we get:

$$h = \frac{\delta}{2} \times \sin \beta \times \sin \beta$$  \hspace{1cm} (5)

Simplifying the resulting expression in its final form, we obtain a calculation formula for determining the maximum (critical) size of the hole of the $D_{кр}$, which can be dusted with this powder without the use of additional parts:

$$D_{кр} = 2h = 2 \times \frac{\delta}{2} \times \tan \beta = \delta \times \tan \beta$$  \hspace{1cm} (6)

For the powders under study, the critical size will be as:

$$D_{кр}^{A-20-11} < 0.63 \delta; D_{кр}^{C-01-11} < 1.583 \delta; D_{кр}^{N3-00-02} < 1.4 \delta; D_{кр}^{C-01-01} < 2.24 \delta;$$

4. Conclusion
1. A method for determining the angle of deposition of powder materials by cold spraying has been developed.
2. Calculation formulas are proposed for determining the maximum (critical) size of the hole $D_{кр}$, which can be sealed by the cold spraying method without installing additional parts.
3. It is established that the maximum diameter of the hole of the $D_{np}$, which can be sealed by cold spraying without the use of additional parts, can be obtained by spraying the powder of the C-01-01 brand at the temperature mode number 4.

5. References

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