Research of terminal soldering technology for auto glass heating systems

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Abstract. The paper considers the issues of technology for soldering a terminal (contactor) to auto-glass heating systems for cars, i.e. technology of soldering metal to non-metal bodies. A technique for conducting an experiment measuring temperature on a setup specially designed for this system is described. The results of experimental studies using various solder compositions are presented. The optimal variants of terminal soldering technologies for auto glass heating systems are determined and presented. Purpose: Experimental study of the soldering process of the terminal to the auto-glass heating system in a specially designed soldering installation. The soldering plant is designed and built using modern computer automation tools. Methods: In the experiments, automatic control systems were used to control the load supply to the soldering irons and the pressure on them. Registration (removal of information) was carried out on the SAMKOON touch panel. Results: Experimental data were obtained that provide temperatures for the optimal soldering mode of the terminal to heating systems. Conclusion: It has been experimentally proven that to obtain the required soldering of the terminal to the auto glass base, it is necessary to create a multilayer base and use hard solder that wets the soldered layer. The temperature holding interval of the soldering iron is in the range of 161 ÷ 242 °C. The composition and weight of the solders used in soldering were also investigated. **Keywords:** soldering, solder, contact angle, solder drop height, terminal, non-metallic body, layer, temperature range, solder composition.

1 Introduction

In a modern car structure, each node of the car is developed and built separately. In each case, research, design and testing of nodes are carried out. Based on the results, a decision on the mass release of the node is applied. One of the nodes of the automotive industry is the production of auto glass for various car brands from side to rearview. But our research is not directed to the development of auto glass technology, they are directed to the study and research of the soldering of the contact (terminal) to the rear window heating system of

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the car. It is known that soldering is mainly used to create contact between metal products. The technology and physical foundations of these processes are well studied [1,2,3].

Specific technologies have been developed for various materials and the use of various auxiliary materials (solders). But the technologies for soldering contacts to non-metallic materials have not been sufficiently studied. In modern conditions, technologies for soldering contacts to non-metallic materials are widely used in technology, which is in great demand. For example, soldering a terminal to auto glass. Therefore, research in this area is relevant.

2 Materials and methods

Soldering is the process of permanently joining metals by means of a molten filler metal called solder and having a melting point below the melting temperature of the parts to be soldered. It should be noted here that the soldering process is used either to obtain individual contacts or to assemble subassemblies or the final assembly of devices. During the soldering process, the mutual dissolution and diffusion of the solder and the base metal occur, which ensures the strength, tightness, electrical conductivity and thermal conductivity of the solder joint. When soldering, the metal of the soldered parts does not melt, which sharply reduces the degree of warping and oxidation of the material. The formation of a high-quality solder joint is obtained in the following sequence [1,6,7,8]:

- preparation of metal surfaces using flux;
- heating above the melting point of the solder;
- displacement of the flux with the help of the incoming solder;
- spreading of liquid solder over a metal surface - wetting process;
- diffusion of atoms from the solid metal phase into the liquid solder and vice versa - the formation of an alloy zone;
- post-treatment of soldered joints - cleaning, when fluxes that promote corrosion are removed.

Practice shows that for a high-quality connection, the heating temperature of the soldered parts in the weld zone should be 50-100 °C higher than the melting point of the solder. The required temperature, in the process of soldering, is obtained by soldering irons. A strong connection of the solder (solder fusion) with the base metal can only be formed if the surfaces of the parts to be soldered are free from oxides and contaminants. To protect the surfaces of the parts to be soldered from intense oxidation as a result of heating, the place of soldering is covered with a flux, which forms a liquid and gaseous barrier between the surfaces of the parts to be soldered and the surrounding air.

The soldering process can be explained as follows: when heated, the auxiliary material (solder) melts and, in contact with the base metal heated, but free from the oxide film, wets it and spreads over its surface. The quality of soldering strongly depends on the degree of wetting. Wetting is determined by the capillary properties and the surface roughness of the parts to be soldered. In technologies, the following requirements are imposed on solders: high mechanical strength of solders under conditions of normal, high and low temperatures, good electrical and thermal conductivity, tightness, corrosion resistance, fluidity at soldering temperature, good wetting of the base body, melting temperature and value determined for this solder temperature range of crystallization. Depending on the melting temperature and the strength of the auxiliary materials (solders) used, soft soldering (soft soldering) and hard soldering (hard soldering) are distinguished [4,5,9].

To assess the solderability of materials, the area and height of the spreading solder over the soldered surface are determined. The spreading coefficient K_p is determined by the ratio:

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$$K_p = \frac{S_p}{S_0} \quad (1)$$

Where, S_p, S_0 spreading area and initial position, respectively.

In the second case, K_p can be determined by the relation:

$$K_p = \frac{(D_k - H_k)}{D_k} \quad (2)$$

Where D_k is the hypothetical solder drop diameter, H_k is the height of the spread solder drop.

The value of D_k is determined without taking into account the gravity of the solder drop by the following expression:

$$D_k = \sqrt{\frac{(6m)}{(\pi\rho)}} \quad (3)$$

Where m is the mass of the solder drop, ρ is the density of the spread solder in the molten form.

To evaluate the soldering process, the above expressions are not enough, since the first expression is $S_p > S_0$, $K_p > 1$, the second expression is $D_k < H_k$, $K_p < 1$. At the same time, these expressions do not take into account the dependence of the spreading area on the mass of the drop and the dependence of the drop height on the tension on the gravity of the solder drop.

To take into account the mass of the initial dose of molten solder and the influence of environmental factors, it is necessary to consider the equilibrium conditions for a "lying" drop on a non-wettable surface.

To take into account the mass of a solder drop in the case of a non-wettable material, we can consider the following scheme (Fig. 1):

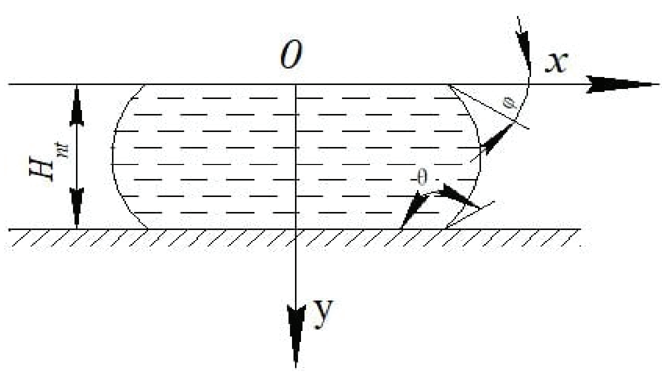

Fig. 1. Scheme of the location of a solder drop on the surface of the soldered material.

For this case, the equilibrium condition can be represented by an expression in the form:

$$\sigma_{nt}\, sin\varphi \left(\frac{d\varphi}{dy}\right) = \rho g y \quad (4)$$

Where, σ_{nt} is the surface tension of the molten solder drop, g is the gravitational acceleration, and y is the current coordinate (solder height).

From the solution of the equation, we can obtain an expression for the height of the solder drop, which depends on the wetting angle:

$$H_{nt} = \sqrt{\frac{2\sigma_{nt}(1-cos\theta)}{\rho g}} \quad (5)$$

Where θ is the contact angle of the surface with a solder drop.

Thus, we can conclude that the height of the molten solder depends on the contact angle of the surface of the soldered material.

3 Results and discussion

Experimental studies have given the following results:

The dependence of the height of the solder drop on the wetting angle.

Table 1. Experimental data.

Solder drop parameters	**Measured quantities**									
θ, deg	90	100	110	120	130	140	150	160	170	180
cosθ	0	-0.17	-0.34	-0.5	-0.64	-0.77	-0.87	-0.94	-0.98	-1
H_k, mm	3.57	3.80	4.13	4.38	4.57	4.75	4.88	4.87	5.02	5.05

It should be taken into account that under actual soldering conditions, the height of a drop of molten solder H_{nt} is always less than the diameter of a hypothetical solder sphere D_k. In this case, the solder spreading coefficient H_p can be calculated using the expression:

$$K_p = \frac{(H_{nt}-H_k)}{H_{nt}} * 100\% \quad (6)$$

The quality of the soldering also depends on the choice of solder for melting temperature and the choice of technology [10-14].

When soldering with soft solders, solders with melting temperatures below 400 °C are used, which provide brazed seams with tensile strengths up to 10 kg/mm^2. The following soft solders are used: tin-lead, low-tin, fusible and special. Tin-lead solders (TLS), having a melting point in the range of 183 ÷ 265 °C, are alloys of tin and lead with the addition of 1.5 - 2.5% antimony.

Used in soldering a metal lead to a glass substrate, the car's solder contains tin and one or more of silver, zinc, bismuth, and lead. The researchers point out that soldering is different in that the flux applied before soldering is not removed after soldering. When a metal lead is soldered to a glass substrate for automobiles, the flux deposited on the glass substrate (silver electrode) remains intact after soldering. For one surface of the metal lead, the amount of solder is used from 0.18 to 1.43 g/cm^2.

Practitioners indicate that the amount of solder from 0.18 to 1.43 g/cm^2 is used for one surface of the metal lead when the metal lead is soldered to the glass substrate for an automobile. In this process, the soldering temperature is 20-200 °C higher than the liquid temperature of the solder [14-16].

Automotive glass is a design in which one surface of the metal lead is soldered to a silver electrode formed on one surface using solder and flux, and the metal lead is made of copper or brass.

In addition, the ratio of the area of the flux deposited on the silver electrode before soldering to the area of one surface of the metal lead is at the level of the lead.

Low-tin and tin-free soft solders: lead (t_{melt} = 327 °C), lead-silver (2.5% silver, t_{melt} = 304 °C), etc.

Low-melting solders (t_{melt} = 60.5 ÷ 145 °C) - alloys of tin, lead, bismuth and cadmium. They are used in cases where a decrease in soldering temperature is required due to the danger of overheating of parts, as well as for “stepped” (second) soldering. The mechanical strength of solders is negligible, and bismuth solders are very brittle.

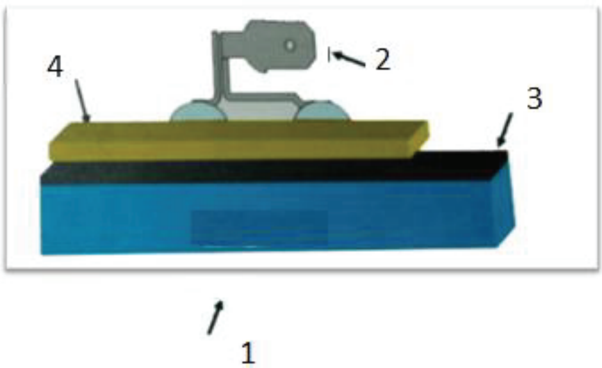

Fig. 2. Structural diagram of the formation of the basis for soldering: 1-glass, 2-terminal, 3-black paint, 4-silver base.

When soldering with hard solders, solders with melting points above 400 °C are used: copper (t_m = 1083 °C), copper-zinc (t_{melt} = 845 ÷ 900 °C), copper-phosphorus (t_{melt} = 700 ÷ 830 °C), silver (t_{melt} = 635 ÷ 870 °C), etc.

Hard solders are divided into refractory alloys with a melting point above 875°C and low-melting alloys with a melting point below 875°C.

Copper-zinc solders are not widely used due to their low mechanical properties. Brass grades L62 and L68 are also used as copper-zinc solders. Copper-phosphorous solders are used as substitutes for silver solders and soft solders. They can only be used for soldering copper and brass parts that do not work on bending, vibration and shock. Soldering of copper with copper-phosphorus solders is carried out without flux; when soldering copper-based alloys, flux is necessary.

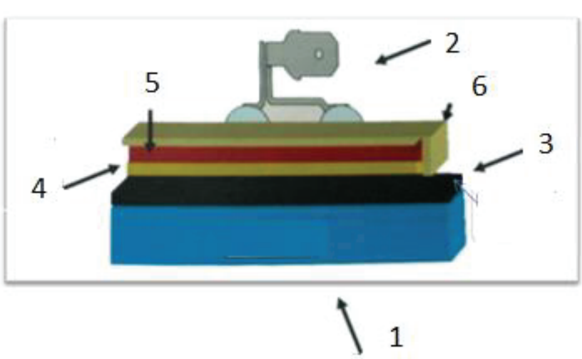

Fig. 3. Block diagram of the formation of a multilayer base for soldering. 1-glass, 2-terminal, 3-black paint, 4-silver base, 5-copper plating, 6-nickel plating.

Copper-phosphorous solders cannot be used for soldering ferrous metals, since they poorly wet these metals and brittle iron phosphides are formed in the boundary diffusion layers. The highest quality is obtained by hard soldering with silver solders, which can be used for soldering ferrous and non-ferrous metals, provided that the melting point of the solder is lower than the melting point of the soldered metal. For hard soldering of aluminium and its alloys, aluminium-based solders are used (t_{melt} = 525 ÷ 580 °C).

To solder the terminal to the glass, the base is covered with black paint and a silver base with a thickness of 7 - 15 μ is placed on it. The terminal is soldered onto the silver base (Fig. 2).

But experiments have shown that good results are obtained when organizing a multilayer base. It additionally created interlayers of copper with a thickness of 3-5 μ and nickel with a thickness of 1-2 μ (Fig. 3).

In our experiments, solders with melting points of 400 °C and below were used. They gave the required results. As indicated above, the choice of solder depended on the composition of the material, i.e. depended on the last layer. Experimentally investigated and obtained the following results (Table 2.).

Table 2. Measured data.

№	Solder name	Composition coefficients, %				Temperature, °C		Appointment
		Sn	Pb	Ag	Bi	Upper range	Low Range	
1	6-4	60	40	0	0	190	183	
2	#500	20	70.5	1.5	8	242	161	Terminal soldering
3	S356	60	36.5	3.5	0	232	178	Pre-soldering
4	#135	30	40	0	30	136	95	Pre-soldering

4 Summary

Experiments were carried out on a specially designed installation for soldering the terminal in a semi-automatic mode. It has been experimentally proved that in order to obtain the required soldering of the terminal to the auto glass base, it is necessary to create a multilayer base and use hard solder that wets the soldered layer. The temperature holding interval of the soldering iron is in the range of 161 ÷ 242 °C. The composition and weight of the solders used in soldering were also investigated.

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