TIN AND ITS USES

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JOINING COPPER CONDUCTORS USING TIN–FUSING

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There are many important applications which require a fast and efficient method of joining copper conductors, and various techniques have been developed as most suitable for particular processes. These include soldering, brazing, welding, and fusing. The last-named is a method used for joining low electrical resistance metals by a combination of heat and pressure, without causing appreciable distortion of the parts being joined. In fusing, the parts are heated and pressed together until all the intervening air is eliminated, forming a surface adhesion contact. The metal surfaces are quickly raised to a high temperature, and this is not normally sustained for longer than 450 milliseconds; for small wires, an average of 64–160 milliseconds is sufficient, and these conditions will also ensure that any insulation on the wires is vaporised at the same time.

This method should be contrasted with resistance welding, where metals are heated locally to a plastic state by passing current through them, and sufficient pressure is exerted to forge or amalgamate them together while they are plastic. In this technique, the current-carrying electrodes have a lower resistance than the workpiece, since it is the latter that must be heated due to its internal resistance. The opposite is the case in the fusing process, where the current-carrying electrodes become hot due to their high resistance; they transfer this heat to the parts being fused, which do not reach a plastic state but are only slightly softened. Consequently, much higher pressures are required in fusing to form a bond, although, as stated earlier, the parts suffer relatively little distortion.

Development of fusing

The method was used in the 1950s for the manufacture of small universal or DC electric motors. Soldering was originally used to connect the insulated lead wires in the commutator slot, but fusing was subsequently found to increase production speed and reliability. As motor production increased further, manufacturers mostly eliminated the need for armature wire slots, which were replaced by commutator fusing tangs. This method is used today in the manufacture of 85% of all DC motor armatures in the U.S.A., and at least 70% in the rest of the world. A commutator fusing machine was patented in 1962 (U.S. patent 3 045,103), and similar equipment is used today; other machines were developed in the early 1960s for other fusing applications, for example, terminating bobbin windings to tang terminals.

In 1964, a development termed "tin-fusing" was introduced, whereby at least one of the conductors is coated with a thin layer of tin. This assists the bonding process such that it becomes feasible to join conductors when they are not being held mechanically together, for example, by a wire slot or tang terminal. The resultant joint is mechanically sound and electrically excellent, and today specific equipment is being produced to take advantage of this process for certain applications.

It may be useful here to compare this technique to that of diffusion bonding, which has been extensively investigated at I.T.R.I. In the diffusion bonding process, a layer of tin provides a low energy diffusion path between two metals brought together at elevated temperature and pressure. The tin melts and increases the effective contact area, while dissolution occurs and an intermetallic layer is initially formed. Continued heating causes further diffusion of tin, to produce a bonding layer of the materials being joined containing tin in solid solution. Essentially, this technique employs moderate pressure and temperature (say 750°C) for an extended period, of the order of minutes. The tin-fusing process, on the other hand, employs high pressure and temperature for a very short time, usually less than one second.

Applications today

One American company, Joyal Products inc., of Linden, New Jersey, markets equipment that employs tin-fusing for two main areas, (i) joining insulated magnet wire to bare, tinned, stranded or solid wire, and (ii) joining armature lead wires to commutators. In the tin-fusing technique, a series of stages are carried out automatically by the fusing machine, usually in less than one second. Firstly, pressure is applied to the conductors that are being joined, until a preset level is reached; at this point, heating is initiated. The tin coating becomes molten, and any wire film insulation is vaporised. The tin helps to clean the copper surfaces, which become bonded together; however, the pressure must be continuously applied until the heating is removed and the joint has cooled, due to the forces that develop during cooling. It is stated that the minimum thickness of tin (at least 99.84 per cent pure) on one of the conductors should be 0.0075 mm for copper and 0.012 mm for brass, while the maximum recommended thickness is 0.01 mm above this. The method is said to be equally effective whether the tin coating is applied by dipping, dipping plus wiping, or electroplating.

The Joyal System 200 Fuse-A-Wire* machine has been designed to join any known insulated magnet wire to bare, tinned, stranded or solid wire, without prior removal of the former's insulation; no additional materials or filler metals are required to form a valid joint, and in fact most copper stranded wire supplied for electrical use (93% in the U.S.A.) is already tinned. The machine is claimed to produce a valid joint (either a splice or pigtail connection) in less than one second. The machine will also cut off any excess wire when forming a pigtail connection. The Fuse-A-Wire system can, in addition, automatically terminate magnet wire to tinned pins that are inserted into bobbins. The value of using this system in the above processes derives from the fact that the normally-used crimp or displacement terminals are no longer necessary for the joint, which can thus be made more economically. The System 200 unit is pneumatically operated and water cooled, and employs a microprocessor unit that controls all the machine's functions, including fusing head movement, heating cycle, and cutting operations.

Another series of units produced by the same company, the Series 79-V, carries out commutator fusing and brazing, according to requirements, and are available in a range of powers from 20 kW to 100 kW. A choice of fusing or brazing processes is available to join armature lead wires to commutators up to 28 inches (711 mm) in diameter. The armature is turned from one commutator segment to another by hand, although various types of mechanical and electronic index mechanisms are available for incorporation into the unit. Parameters concerned with the fusing or brazing process are again microprocessor-controlled. Fusing copper leads to a copper commutator normally takes under one second, while brazing time is normally under three seconds per commutator segment. The tin-fusing process is thus quicker, and also eliminates the cost of the brazing alloys. In each case, a joint temperature of 760°C-820°C is employed; however, the pressure used in tin-fusing is at least ten times that required for brazing.

The quality and consistency of joints made by this process are dependent on a range of factors, the most important being the control of heat to the joint. Accurately monitoring and controlling temperature by the use of infra-red transmitting optical fibres is claimed by the company to represent a breakthrough in the brazing and tin-fusing of commutators. The temperature is measured by the infra-red emission from the joint, by a patented Thermal Monitor/Controller. A fibre optic probe from the latter surveys an area 0.5 mm across, and can be targeted with the aid of an internal light source. The Thermal Monitor/Controller ensures that the temperature of the joint area reaches a pre-set level for a pre-set time, and that the cycle is as required.

The tin-fusing technique for producing copper-to-copper joints has already proved itself in the mass production of automobile starter motors, and has the potential to gain much wider acceptance in other areas where mechanical termination systems are presently used.

Reference:

''Tin-Fusing" by Allan Warner, Proceedings "Coil Winding 1984", Internatiorial Coil Winding Association Inc., November 13th-15th 1984

*Trade name