Aluminium brazing by induction heating

Special units for induction heating enables the brazing of aluminium parts with high reliability and repeatability. The following report describes that the special nature of these induction units enables also the soldering of copper or, with special solder, the realisation of the connection of aluminium and copper parts.

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Aluminium brazing technologies

The previous aluminium brazing processes were very problematic because of the special properties of aluminium. When heated the surface of the material will get a thin oxide layer (Al_2O_3) immediately by heating in the air. The oxide layer is preventing the solder to make the connection between two aluminium parts, which we want to solder together. That is possible to solve using the proper soldering fluid, which is preventing the forming of the oxide at higher temperatures. This fluid should be by the mentioned high temperatures very aggressive in order to prevent the mentioned oxide forming. The second problem are the aluminium properties at the temperatures near the melting point. By these temperatures the aluminium is becoming very soft and can not bear a lot of weight. The soldering material should have the melting point near the melting point of the original aluminium parts. That means, that it is necessary to have very precise temperature control to achieve the proper aluminium brazing process.

Till now in general there were only two ways for brazing aluminium parts. That was heating in the normal chamber furnace with the heating temperature control and the heating by gas flame. In the chamber oven the temperature is relatively simple to control, but by the flame it is absolutely necessary to have very precise temperature control and the regulation of the flame is quite complex.

Fig. 1: 10 kW induction heating converter

In the furnace it is necessary every time to put the complete charge of the material inside to be treated. The brazing quality is very good because of very good temperature control, because of very uniform heating and because of the possibility of the protection atmosphere application. By gas flame heating there is already localized heating, but the procedure is relatively long and the results could differ very much because of very problematic gas flame control. These factors are the reason of relatively bad soldering quality with very different results in quality and soldering microstructure.

Till now the induction heating was not very much applied in spite of that, that it is by that way of heating very easy to concentrate the energy and with that the heat on very defined places. Also the heating procedure could be very fast. The reason of avoiding induction heating equipment for the mentioned purposes also was the problematic of the efficient heating of good non ferromagnetic conductors by means of induction. The problem is lying in the correct appliance and inductor coils design. Aluminium itself is namely very good conductor with low electrical losses, when the electrical current is flowing through it. The temperature conductivity of aluminium is in comparison for instance with steel, much higher – almost about three times. The appliance should therefore generate the strong electromagnetic field in the inductor coil to be able to reach very high current density in the surface of the heated material. Only by that way it is possible to achieve the proper heating effect. In our enterprise Induktio, Ljubljana, Slovenia, we have succeeded to develop the induction heating devices, which are able to fulfil the conditions, described above. The heating and brazing experiments with such the equipment show very promising results and a lot of possible benefits of such the process. Because of that and because of the interest from the industry we have decided to develop the special device only for the purpose of aluminium heating for hard brazing. **Fig. 1 and 2** are showing the corresponding equipment.

The induction heating equipment

The induction heating is a well known process for industrial metal heat treatment. The use could be very different and the induction heating process could be applied for the following purposes: glowing, surface and through hardening, melting, hard and soft brazing, tube welding etc. The induction heating technology is limited on heating of metals, which could be ferromagnetic as well as non fer-

Fig. 2: Inside of 10 kW induction heating converter

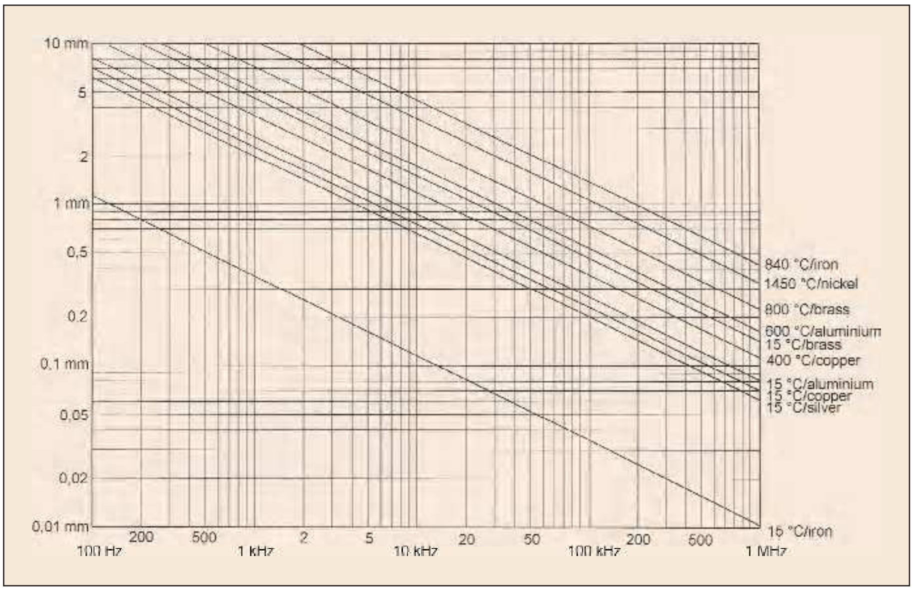

Fig. 3: Penetration depth of the induced current in dependence on the frequency and the material

romagnetic. Induction heating of non ferromagnetic materials and special of very good conductors as for instance copper and aluminium is in praxis very hard to realize and demands the special construction of the device.

In order to understand the problematic of induction heating of non ferromagnetic metals, which are good conductors we have to explain the fundamental principle of induction heating. Induction heating is caused by eddy currents induced in the work piece. Penetration depth (in this depth only about 1/3 of the surface current is still active) of such currents depends upon the material and the frequency applied (**Fig. 3**). Because of physical properties using the same working frequency, the ferromagnetic materials have higher penetration depth in comparison with non ferromagnetic metals, which are good electrical conductors like aluminium, copper and other similar metals.

The thermal efficiency of induction heating could be calculated from the following approximate Kretzmann formula:

$$\eta_{th} = \frac{1}{1 + \frac{D^2}{d^2}\left(1 + 6{,}25\frac{\delta^2}{d^2}\right)\sqrt{\frac{\rho_1}{\mu\rho_2}}}$$

η_{th} = thermal efficiency

D = diameter of inductor

d = diameter of work piece

δ = penetration depth

μ = permeability

ρ_1 = resistance coefficient of inductor

ρ_2 = resistance coefficient of work piece

So, in principle it is then necessary to have lower frequency to achieve the same current penetration depth in the non ferromagnetic metal, which is good conductor. The next problem by the good electrical conductor is, that because of very good conductivity in the material, there is poor resistance heating of such material, when putting into electromagnetic field. Therefore we need very strong electromagnetic field to achieve the similar heating effect as by ferromagnetic materials. **Fig. 4** shows how to detect current along the axis of the induction coil. **Fig. 5** shows the current in a conductive piece.

Taking all the described effects into account in our enterprise Induktio we have designed the special induction heating source, intended only for the purpose of very effective induction heating of very good metal conductors. Because of special properties of the oscillator circuit, it is generating very high voltage and current directly in the induction coil. This generation is enabled by the special design of the series quasi resonant converter, driven by power IGBT power transistors.

The another problem to make such equipment useful for the industrial use and to realize the repeatability of the process in series industrial production, where the brazing quality should not vary and as small, as possible throw out is expected, we had to design the proper induction coils for heating different aluminium parts. For some simple shapes of such aluminium parts there was no special problem, but for some more complicated shapes, there was necessary to apply the special inductor coil design (**Fig. 6**).

In the present diagram there is the sample of the brazing process by induction heating. The first very high power is applied, then the power is two times reduced, but the temperature is growing the first very fast and on the end is stabilized on the value, where the

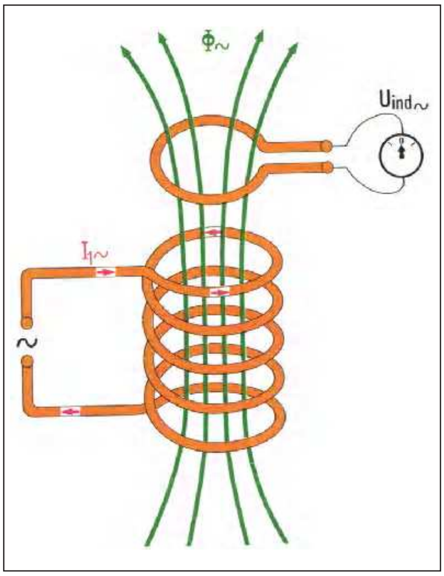

Fig. 4: Induced current in one turn coil positioned in the field of multi turn coil called inductor coil

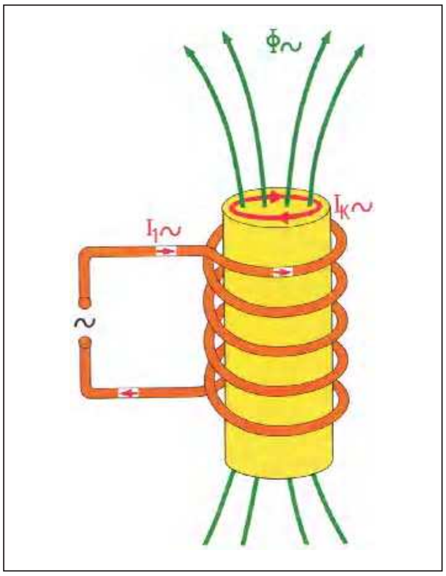

Fig. 5: Induced current in the electrical conductive piece, positioned in the field of induction coil

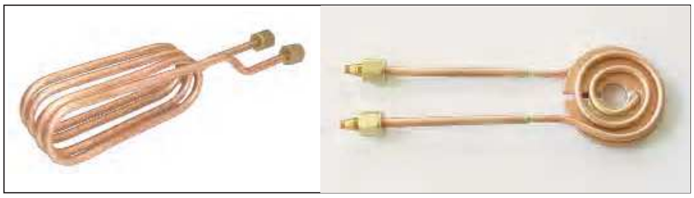

Fig. 6: Induction heating coils for Al brazing purposes - examples of the design

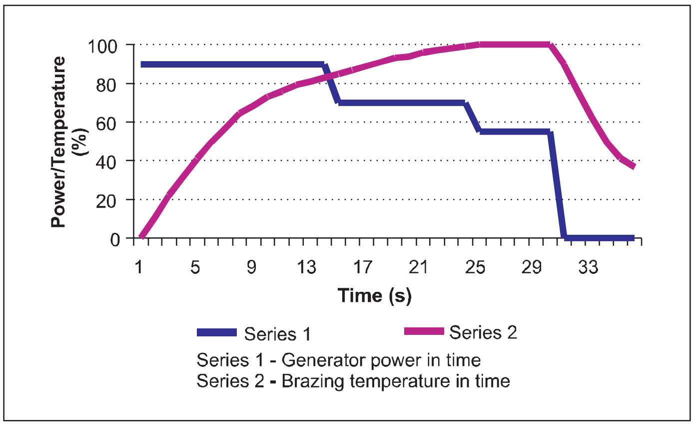

Fig. 7: Induction brazing – Power / Temperature

brazing material is flowing good. There is some typical value of the time, where the brazing material should flow to get the good connection between two pieces. The temperature is in %, where 100 % means the melting point of the braze material. The characteristic melting temperatures of the material for Al hard brazing is between 575 and 585 °C (**Fig. 7**).

The electromagnetic field should be of proper density in according the work piece shape. It is necessary to design the inductor coil, that there is no local overheating of some parts of the work piece, where the mass is smaller, than on the other part of the work piece. In order to solve these problems have made a lot of experiments and the result of these experiments it was the inductor coil design, where the transversal component of the electromagnetic field had the priority. In the transversal electromagnetic field is the heating effect very dependable upon the work piece surface distance from the coil. With the proper coil design is so possible to achieve the heat concentration exactly on the parts of the work piece, where it is more mass of the material and therefore to prevent overheating of parts, which have smaller mass.

Fig. 8: Brazing with different materials (Cu/Al), Al/Al) by induction heating

By all brazing processes, there is necessary to preheat the material on the proper temperature to make the solder liquid and then to hold the temperature for some time to enable the solder to flow in the gap between two pieces, which should be brazed together. The solder is flowing in the gap between two pieces due to the capillary effect and because of that the gap should not exceed about 1/10 mm. The flux, which is added on the beginning of the process, is disabling the oxide forming on aluminium surface and by that enabling the clinging of the solder on aluminium surface. As we have already described, the melting points of the solder and aluminium material, which should be brazed together, are normally very closed and that is the reason, that it is necessary to reduce the induction heating source power, when the liquid state of the solder will be reached. That reduction is in principle with our induction heating converters, which are driven by PLC system Simatic S7, not problematic.

The problem is to detect the proper moment to reduce the power. Therefore we have made the experiments with the pyrometer for the detection of proper temperature and then to control the power of the converter. After these experiments and not very promising results, we have decided not to apply very expensive pyrometers for that purpose. The temperature measurement should be namely very exact, but there are a lot of possibilities to make these measurements incorrect. The main reasons were in the different aluminium surface brilliance and with that changeable emission factor, further the influence of flux presence and steam because of heating, with the result of very unreliable temperature measurement.

After the decision not to apply the pyrometer to make the temperature measurement the optical pyrometer, we have decided to make the empirical heating solution. After a few experiments with different heating powers and

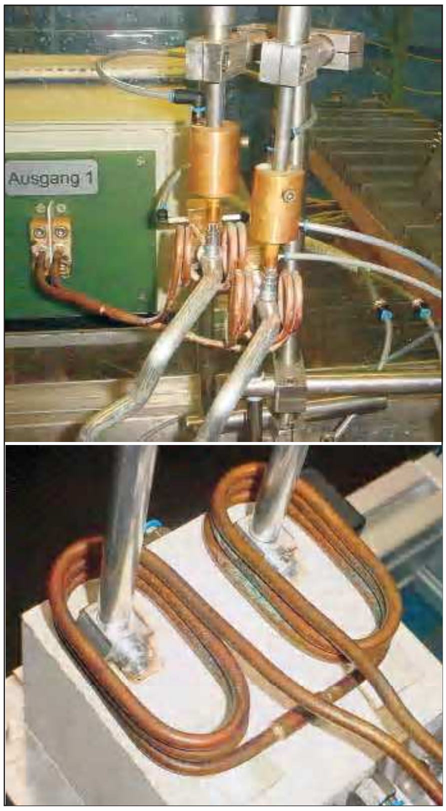

Fig. 9: Piping for car condition

different heating times we have made the conclusion to program the proper heating curve of the material on the basis of our empiric experience. On the beginning of the process, there is necessary to apply very high power in the work piece to achieve fast heating. When we reach the temperature, near melting point of the solder, it is necessary to reduce the power and after reaching the melting point is necessary further to reduce the power only to hold the temperature for a certain time to enable the solder to flow properly in the gap between two parts, which should be brazed together. We realized that by the special program for each work piece. The program has the possibility to program three different heating powers and three different heating times in the connection with mentioned three different heating powers. For each different work piece is by that way possible with experiments to define the mentioned parameters and the to program them into the SPS system. The mentioned experiments do not take a lot of time and the solution appears in practice very useful, economic and reliable.

The results of the described experimental research and work were very useful for the industrial application of induction heating for aluminium and also copper brazing (**Fig. 8**), which is in principle not so delicate as aluminium brazing itself. The application of aluminium brazing by induction heating has showed a lot of benefits in comparison with other ways of aluminium brazing. The most important are the following benefits:

- quality of the junction, which is comparable with that, achieved, by brazing in the chamber vacuum oven
- good repeatability of the process and by that very reduced throw out
- very high machine capacity and by that very high productivity in comparison with other brazing processes
- local heating, connected with high efficiency of modern transistorized induction heating equipment and by that considerable saving in energy.
- environment friendly process

With some special solders and fluxes excellent results can be achieved by brazing Cu/Al and Al/Al parts also. Some special applications are shown in **Fig. 9**.