# Optimization of Energy Consumption and Microstructure Aspects on Brazing of Aluminum Tubes for Automotive Industry

MIRCEA NICOARĂ
mircea.nicoara@mec.upt.ro
AUREL RĂDUȚĂ
aurel.raduta@mec.upt.ro
COSMIN LOCOVEI
cosmin.locovei@mec.upt.ro
VIOREL AUREL ŞERBAN
viorel.serban@mec.upt.ro
Department of Materials and Manufacturing Engineering,
POLITEHNICA University of Timişoara
Bd. M. Viteazu 1, 300222 Timişoara,
ROMANIA
ERIC LABBÉ
eric.labbe@univ-reims.fr
ALAIN LODINI
alain.lodini@univ-reims.fr
Institut de Formation Technique Supérieure Charleville-Mézières,
Université de Reims-Champagne-Ardenne
7 Boulevard Jean Delautre BP 50028 08005 Charleville-Mezieres,
FRANCE

*Abstract:* - Assemblies of extruded tubes fabricated from aluminum alloys represent a major choice for the fabrication of fluid circuits in automobile construction. Torch brazing is the most employed joining technique for mass production, but it implies serious drawbacks caused by frequent structural defects of the material and large consumption of fossil energy. Experimental work with inductive heating on two different grades of aluminum alloys proved that use of induction could produce high quality joints, having favorable material structure, lower incidence of brazing flaws and shorter processing cycles. Energy consumption for inductive brazing is considerable lower and eliminates the burning of fossil fuel, as well as emission of carbon dioxide.

*Key-Words:* - induction brazing, torch brazing, energy consumption, microstructure, emission-free technologies

## 1 Introduction

Aluminum alloys represent the first choice for applications where lightweight has to be completed with high mechanical properties, corrosion resistance and efficient processing.

Aluminum parts have been used in recent years at larger scale in some industrial domains, such as automotive industry, aeronautics, household devices etc. One of important advantage provided by the use of aluminum alloys is that large assemblies can be easily produced by mean of brazing.

An important case for employment of aluminum tubes assembled by mean of brazing is represented by the complex systems for fluid circulation of modern cars.

There are some important advantages of brazing which are the reasons for extensive use:

- The brazing filler is also an aluminum alloy, assuring a mechanical resistance of the joint which is comparable with the base material. The meniscus surface formed by the filler metal is ideally shaped for good fatigue properties;
- Joining technologies consist mainly in heating around 500°C, without controlled atmosphere, and a relatively short time cycle. Since no intermediary component and no additional machining are required, this will finally result in a cost-effective solution;
- Since processing temperature is lower than in the case of welding, energetic costs are inferior. Structural changes in material are also reduced, conserving both mechanical properties and corrosion resistance of aluminum alloy, if technological parameters are correct [1].

The alloys for automotive industry usually belong to the aluminum - manganese (3000) and aluminum - magnesium (5000) families, for both mechanical and corrosion resistance reasons. The fabrication technology for the tubing components is based on extrusion.

The brazing filler is also an aluminum alloy, which has a melting temperature lower than the base material of the joint parts, having a near-eutectic concentration in Al-Si system. Therefore, the most sensitive technological problem is to provide a temperature distribution that allows melting of the filler, i.e. higher than 577°C, but should not produce heating above 625°C, which could produce melting in the base material.

Convenient temperature distribution is relatively difficult to achieve, since aluminum alloys have a high thermal conductivity. For localized heating a correct heating distribution could be seriously influenced by several factors: changes in environment state, contact with positioning devices, power variation of the heating source etc.

The most frequently method used for industrial applications is considered to be the torch brazing, since the technology requires only simple equipment and brief personal training. However torch brazing has proved to have serious limitations that require optimization for both economical and technical reasons [2]:

- High temperature of the flame could easily produce overheating of the joint area and structural flaws, such as accelerated corrosion, melting of grain limits and increase of grain size, which could produce fragility and lack of proper sealing. This effect of considerable grain size enlargement is enhanced by the fact that in some cases the material could be plastically deformed at higher ratio near the joining area. An analysis of more frequent structural defects that could occur during torch brazing is presented elsewhere [3];
- Flame shape and temperature is influenced by many factors, such as pressure, flowing rate and purity of the combustive gas, presence of air currents, shape and position of burners, etc., which represent possible causes for process instability and higher scrap percentage.
- The heating is normally localized on small material spots, which is in contact with the flame. This fact causes an initial non-uniform distribution of temperature, which requires pre-heating and pauses between heating phases. The result will be a longer brazing cycle and an increase of energy consumption;
- Generation of flame is based on burning of gaseous hydrocarbons, usually propane, an environment unfriendly solution, with considerable emission of carbon dioxide;

Inductive brazing has been proved lately as a promising solution in automotive industry, based on higher stability and precision of electrical processes, as well as the use of electric power, considered to be friendlier to environment [4].

## 2 Materials and experiments

The main objective of present researches consists in development of a brazing technology for aluminum tubes based on inductive heating, aimed to replace the classic torch brazing. The processing technique should provide process stability, precise parameter control and optimum quality for the joining area. Aside elimination of hydrocarbons burning, the total energetic costs should be at reasonable level for economic efficiency.

Experiments have been carried on for brazing of an assembly with components at a 90 degrees angle, which is presented in figure 1. Testing has been made for components fabricated from EN AW 3103 (AlMn1) and the brazing filler was a binary aluminum-silicon alloys with near eutectic composition of 11,7% silicon.

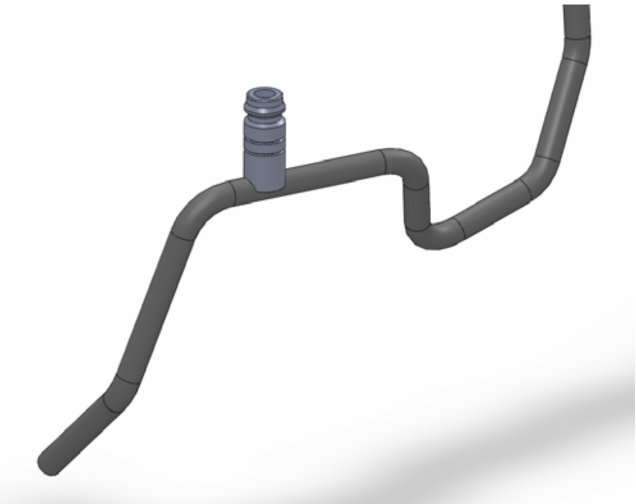


Fig 1. Construction of the brazed assembly.

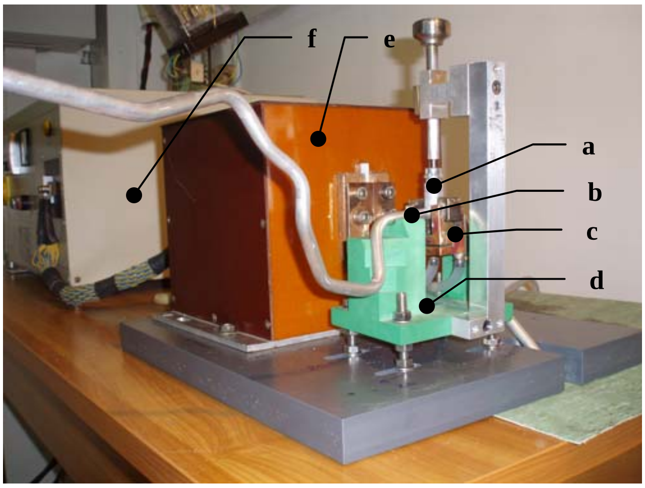


Figure 2. Experimental setup for induction brazing: a - vertical tube; b – horizontal tube; c – inductor; d – positioning device; e – transformer; f – induction generator.

Special positioning devices and inductors of original conception has been used for inductive brazing. A high variable frequency laboratory generator with a 12 kW nominal power has been used to provide energy to the brazing inductor. Appearance of experimental setup is presented in figure 2.

Process parameters that have been determined for inductive brazing of the EN AW 3103 aluminum alloys are presented in Table 1.

Table 1. Parameters of induction brazing.

| Parameter | Value |
|---|---|
| Duration [s] | 30 |
| Electric tension [V] | 340 |
| Electric current [A] | 10 |
| Induction frequency [kHz] | 90 |
| Brazing filler | AlSi12 Ø1,6 mm |
| Oxide removal | NOCOLOK® Flux |

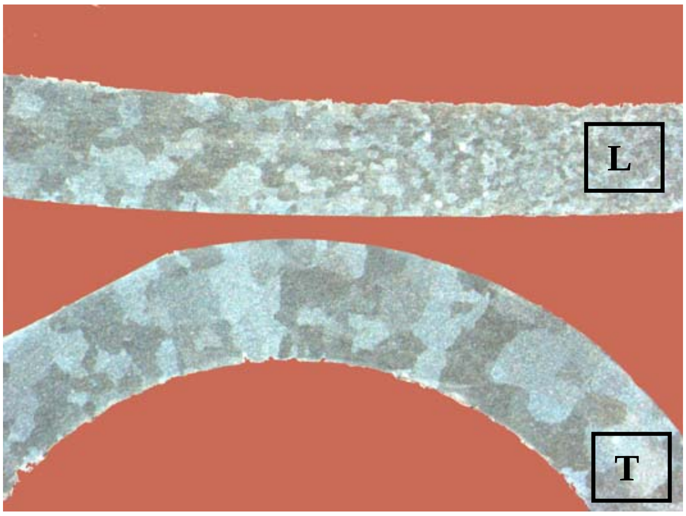
Evaluation of brazed assemblies has been based on microstructure investigations, as well as technical, economical and environmental considerations. The reference for evaluation has been an existing solution, based on torch brazing, which is applied on industrial scale.

## 3 Microstructural analysis

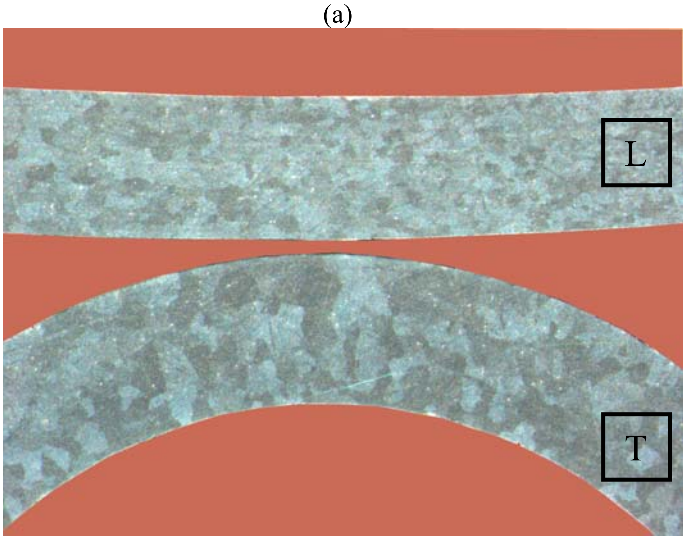
Comparative evaluation of joints quality for both torch and induction brazing has been based on metallographic investigations with optical microscopy. Resulting materials structure after induction brazing has been compared for reference with torch brazed joints considered as conformal for industrial fabrication. In order to determine significant increase of grain size, lack of filler infiltration, pronounced corrosion or other structural flaws, longitudinal and transversal sections have been performed through the joint area, in order to evidence the assembled tubes and the brazing filler.

Figure 3 presents the resulting microstructural appearance of the horizontal tube made of EN AW 3103 alloy after both torch (a) and inductive (b) brazing, in the proximity of the joining area, within the heat affected zone.

As it can be noticed from the longitudinal section L, there a grain size increase toward the left side of the image, which is closer to the joint. On the transversal section T performed in the joining plane, grain size is significant growth of the grains, which indicates heat exposure. Remarkably, the increase of grain size is much lower when inductive heating is applied, which mean that heat exposure and resulting effect, such as material fragility, are less likely to appear.



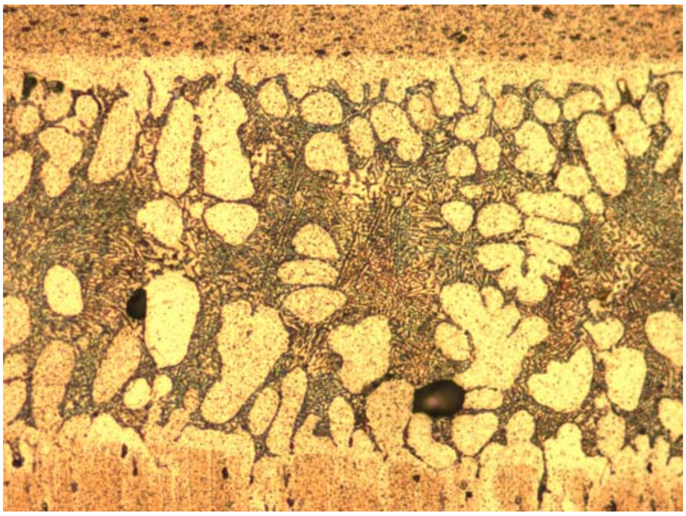
(a)



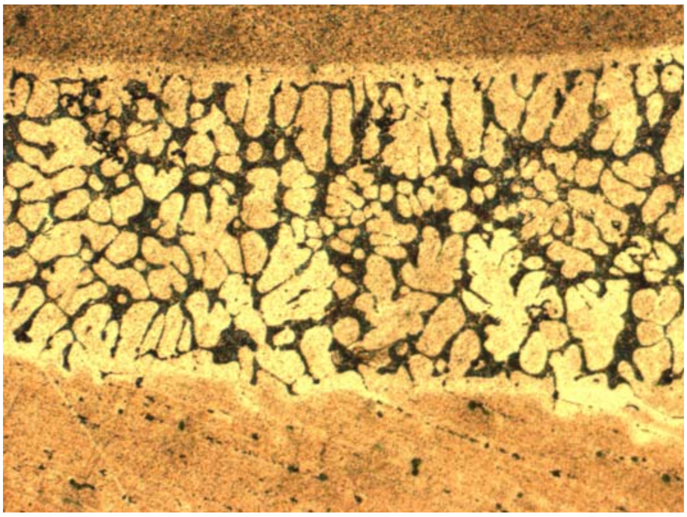
(b)

Figure 3. Microstructure of a 3103 aluminum tube:
(a) torch brazing; (b) induction brazing (OM 12,5x).

There are some noteworthy structural differences between torch and inductive heating, if the brazing filler is considered (figure 4).



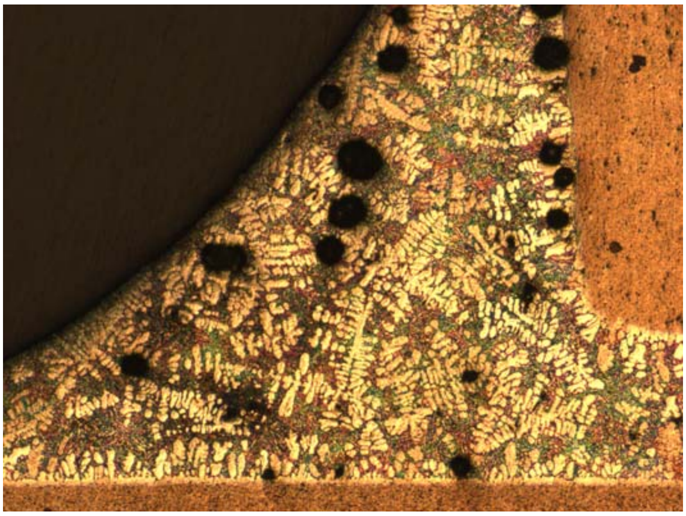
(a)



(b)

Figure 4. Microstructure of the brazing filler for brazing of aluminum 3103 tubes in longitudinal section: (a) torch brazing; (b) induction brazing (OM 200x)

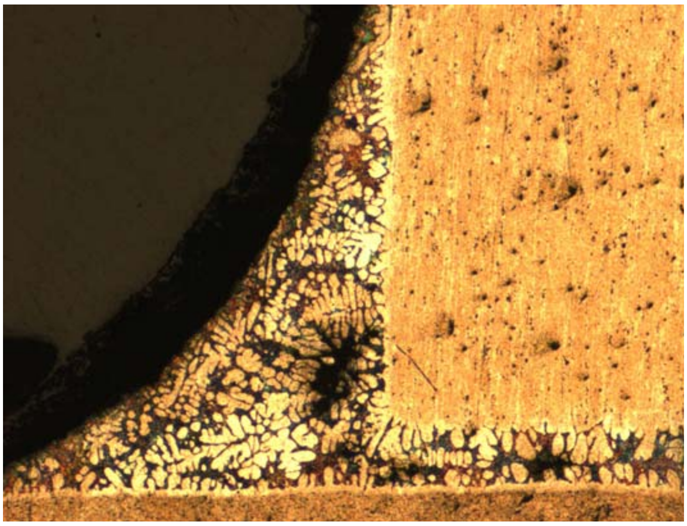
Although adhesion to base material is good for both cases, constituents are finer in the case of inductive brazing. This fact could be explained by the lower quantity of heat that is used for inductive melting of the filler, which will eventually produce a higher cooling rate.



(a)

Induction heating is also conserving a good infiltration between components (figure 5b), and proper humectation of the tubes. In comparison with torch brazing (figure 5a), there is a lower number of pores that could suggest reduced shrinkage.

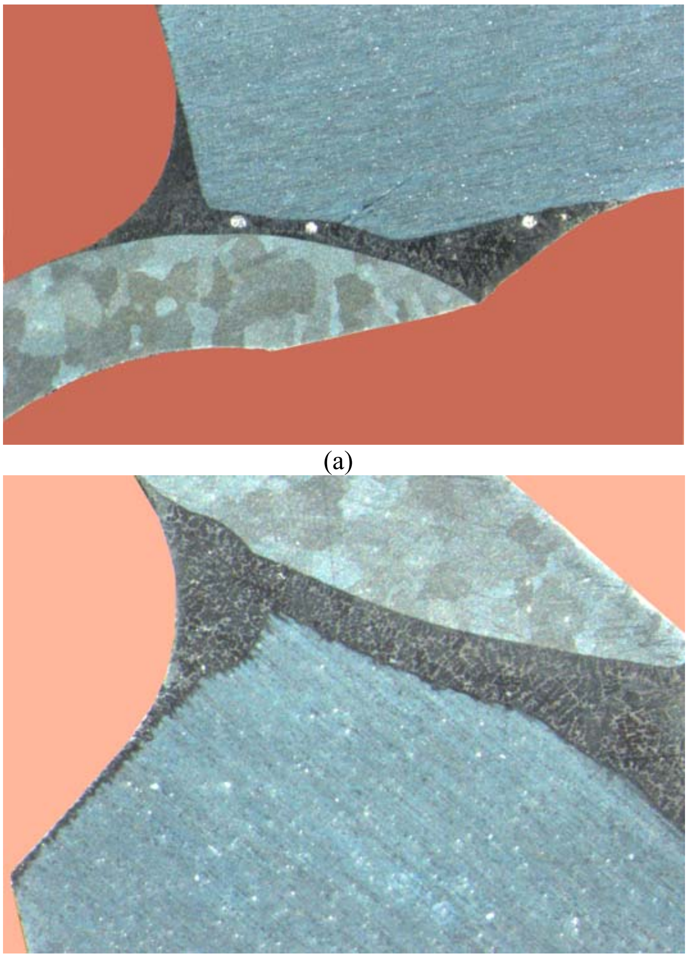
The favorable appearance of joint, for both torch (figure 6a) and induction (figure 6b) brazing can be documented also in transversal section. As seen in figure 6, there is a complete infiltration of brazing filler between components, and a complete contact, which signifies good humectation during filler melting.



(b)

Figure 5. Microstructural appearance of the joint: (a) torch brazing; (b) induction brazing (OM 50x).

Another important feature for both cases is the favorable meniscus surface of the filler, which provides good fatigue resistance.



(a)

(b)

Figure 6. Macroscopic appearance of the joint in transversal section: (a) torch brazing; (b) induction brazing (OM 12,5x).

## 4 Analysis of brazing process

An important aspect for economic feasibility of induction brazing is the energy consumption for each brazed assembly. The reference value is represented by the energy consumption for torch brazing, which results as an estimation of the heat dissipated by the LPG burners. The heating is produced by two torches that are used for heating, each of them having a nozzle of a 0,3 mm diameter, and supplied with a gas pressure of 1,5 atmospheres. The total brazing cycle is about 60 seconds, divided in two periods of pre-heating and one final heating, the power of each torch for an average combustion value for LPG of 95.8 MJ/m³N could be evaluated at 5,4 kW. The total energy need for torch brazing is about 648 kJ.

An estimate of energy cost for induction brazing is based on the nominal power of 12 kW of the induction generator, which is functioning at 70% of the maximum capacity, i.e. approximately 8,4 kW, for a brazing cycle of 30 seconds. The resulting specific energy consumption for each brazed assembly could be approximated to 252 kJ. The estimated values for both brazing methods are represented in figure 7.

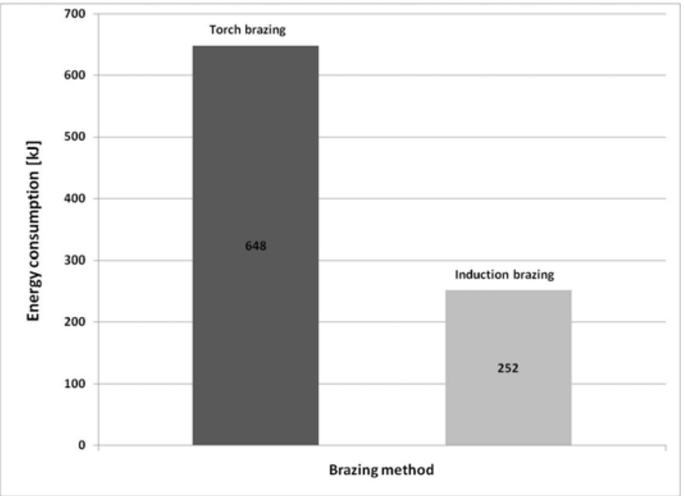


Figure 6. Estimation of energy consumption for torch and induction brazing.

It may be noticed that induction brazing has much smaller energy consumption. Since the estimated power of the torches and inductor are similar, 8,4 kW for inductor and 10,8 kW for the two torches, the much shorter induction brazing cycle could be determined by a more localized heating, and a more uniform temperature gradient within the heated zone. Higher energetic density of induction heating will also allow shorter heating cycles and reduction of heat losses by convection and conduction. The environmental superiority of induction brazing is determined by the fact that no direct emission of carbon dioxide are produced, since the source energy is electric and there is no combustion process. Structural flaws of the base material and brazing filler, which are quite frequent and are mostly produced by factors related with the flame stability, are less likely to occur during inductive brazing, since all the setup parameters are electric. For this reason, even during experimental testing the induction brazing has proved to be very stable and reproducible.

## 5 Conclusions

Induction brazing has some obvious advantages over other brazing method, especially over torch brazing, still dominant in aluminum tube assembling for automotive industry. On a middle term, general interest for development of emissions-free technologies, and large-scale use of electricity, increasingly produced by mean of regenerative source, is expected to raise interest for induction-based brazing of aluminum. Higher energetic density, and better control over the heating zone, allows reduction of processing time and energy consumptions, providing significant reasons for development, especially in automotive production, where large-scale fabrication amplifies technical and economical benefits. Therefore reduction of cost with energy and manpower, tend to overrule concern for more complex and expensive equipment required by induction brazing.

Regarding the quality of brazed joint, investigations have proved that induction could produce more favorable microstructure, because of reduced heat exposure, at lower temperature level and duration, which will virtually eliminate defects related to overheating.

*References:*

[1] J. Lacaze, S. Tierce, M.-C. Lafont, Y. Thebault, N. Pébère, G. Mankowski, C. Blanc, H. Robidou, D. Vaumousse and D. Daloz, *Study of the microstructure resulting from brazed aluminium materials used in heat exchangers*, Materials Science and Engineering: A, vol. 413-414 . pp. 317-321.

[2] American Welding Society, *Brazing Handbook*, American Welding Society, Inc., 1991.

[3] M. Nicoară, A. Răduță, C. Demian, C. Locovei, E. Labbé, Some Metallographic Aspects of Sealing Defects at Brazing of Aluminum Alloys Tubes, *Scientific Bulletin of the "Politehnica" University of Timisoara, Transactions on Mechanics*, Tom 53(67), Fasc. 4, 2008 pp. 87-93.

[4] S. Zinn, S.L. Semiantin, *Elements of Induction Heating: Design, Control, and Applications*, Carnes Publication Services, 1988.

[5] R. C. Goldstein, V. S. Nemkov, R. T. Ruffini, Computer-assisted induction aluminum brazing, *Industrial heating*, vol.70, No.11, 2003, pp. 45-48.