Researches regarding glass joining using hybrid microwave-resistance thermal source

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1. Introduction

The paper aims to present preliminary researches in microwave-resistance hybrid welding of the glasses. Glass welding through microwave heating is possible according with previous researches. However, during the cooling time of the joined glasses, some cracks could appear due to the high difference between the temperature of the sample and ambient temperature. In order avoid this phenomena, a second thermal source consisting in an electrical resistance oven was applied in order to perform a controlled cooling process. Regarding, the controlling the cooling of the joined glasses, a step by step reduction of the microwaves power should be enough to obtained a smoothly transfer of heat from the joined glasses down to the ambient temperature. However, the glasses behavior in microwave field is very unstable [1, 2]. They have low absorption of the microwaves properties in ambient temperature, so, the conversion of the microwaves energy into heat is very low, but these properties increase with high gradient of conversion when the glasses are heated. This behavior is called thermal runaway of the material and the temperature increases very fast and the process cannot be controlled. Previous researches have shown that during the cooling process controlled by the reduction of the microwaves power, the temperature is not stable and cracks appear or the quality of the weld is very low.

2. Hybrid heating-cooling system

The hybrid heating - cooling system (figure 1) is composed of common heating chamber for two distinct devices: industrial microwave generator with single direction and two ways for the microwave beam and classic resistive oven dedicated to heat-treatment processes. The designing of the common chamber was based on specific criteria which are related to the electromagnetic phenomena and to the process purposes (figure 2).

The microwave component of the system is ended before the heating chamber with an automatic tuning system. The technical characteristics of the magnetron are:

- Anode voltage: U_{anode} = 3.5 kV
- Input voltage: U_{source} = 400 V AC
- Water cooled generator (Magnetron)
- Output power from 0 to 1250 W, adjustable according to the purposes.

Within the heating chamber it can be introduce for welding samples with dimensions up to 45 mm height and 70 mm length. The heating chamber is connected to 1 temperature sensors (IR pyrometer; with measurement range from 0 to 700 ^{0}C)

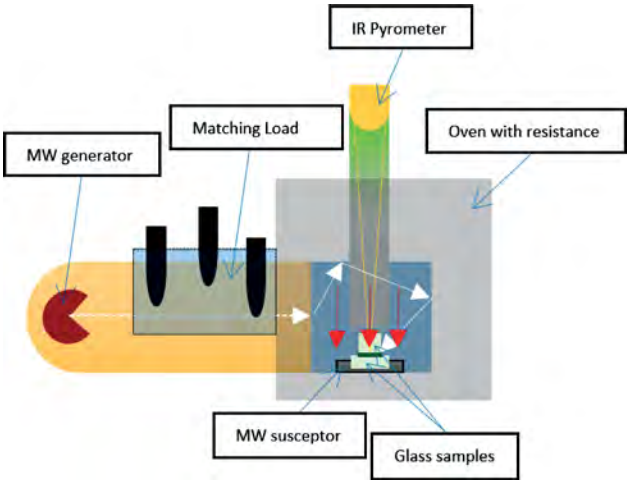

Figure 1. Principle of MW-R heating-cooling system.

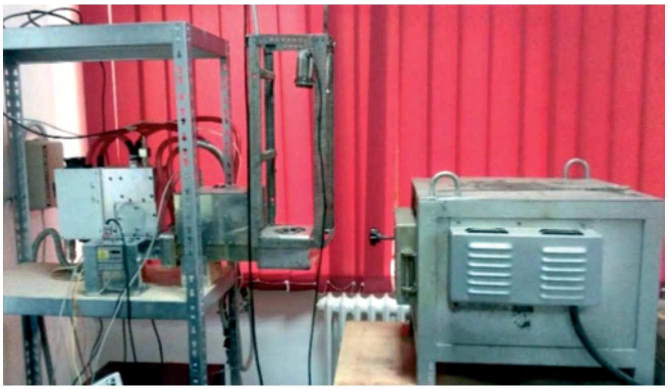

Figure 2. MW-R hybrid heating system.

and a webcam for video recording of the process. It is, also, connected to microwave sensor in order to detect any leakage of the microwave during the heating process, which is dangerous for human health. The samples are place inside the microwave heating chamber which is introduced in the resistance industrial oven.

3. Experimental program

The samples (figure 3) used in experimental program were classic glasses having square shape with side of the square equal with 300 mm and thickness of the glass 5 mm. They are place inside the microwave heating chamber accordingly to figure 4.

The heating process starts with a rapid heating at a power injected by the microwave generator up to 10%, the equivalent of 125 W. The process is maintained until the temperature reaches 530^0 C. At this time the bottles begin to stick. However, this is

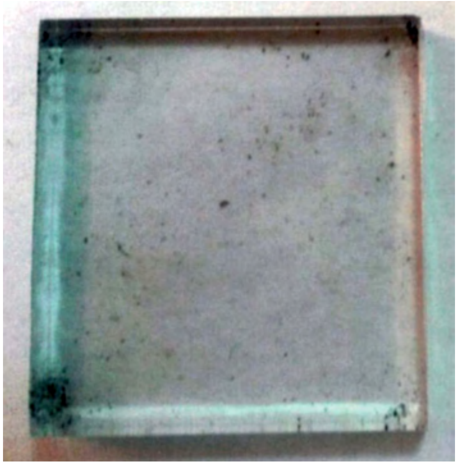

Figure 3. Samples used for joining.

Figure 4. Samples în microwave heating chamber.

not the merger, and then the next step is that after 5 minutes of thermal stabilization at this temperature level, the power gain is 170 W. This is the second step of the heating process and will be maintained until the temperature reaches 750^0 C. At this temperature the glass begins to melt and the process will be maintained at this level until a complete fusion is achieved. However, due to the fact that the bottles will become good microwave absorbers and the conversion of the electromagnetic energy into heat will be higher, so the thermal gradient will increase, a reduction of the injected power around 150 W is required. After 10 minutes, the power will be reduced slightly keeping a controlled cooling run of about 5^0 C / min. This cooling slope is very important because the bottles are in full solidification when cracks can occur if the cooling is too fast. When the temperature reaches 530^0 C, the magnetron-generated power will have to be reduced to 125 watts to maintain this level when the unwanted bubbles inside the joint are completely absorbed. During the microwave heating process, the second thermal source is started and the temperature inside the industrial oven will be increased up to 400^0 C. This will allow that after the reducing of the microwaves power, the samples to benefit by quasi-thermal equilibrium during cooling process.

4. Results and discussions

During the welding process, the temperature was not uniform distributed in material with the highest point of temperature in the welding zone. A video snapshot of the thermal field during the heating process is presented in the figure 5. This phenomena is explained by to considerations:

- In the joining area between the glasses, the defects created by cutting glass contribute to the improvment of the microwave absorbance and therefore to the higher rate o conversion of the microwave energy in heat [3, 5]
- The electrical alternantive high frequency wave has the amplitude in the point of welding. This is due to the matching load impedance performed by auto-tuning device (figure 6).

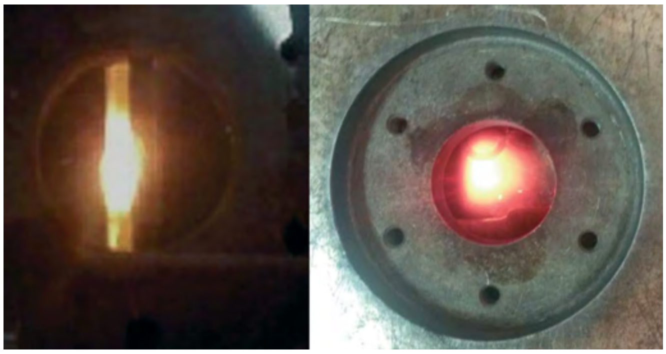

Figure 5. Thermal field evolution during joining.

A thermal cycle can be developed in order to have a starting point for further researches in microwave-resistance welding of the glasses. The cycle has been elaborated based on experimental program.

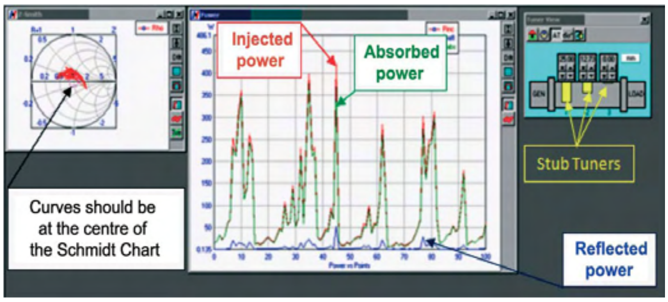

Figure 6. Matching load impedance process [4, 6].

The heating-cooling process with actions of the both thermal sources and timing of the heating and cooling process is presented in figure 7. Without controlling process the glasses cracks (figure 8).

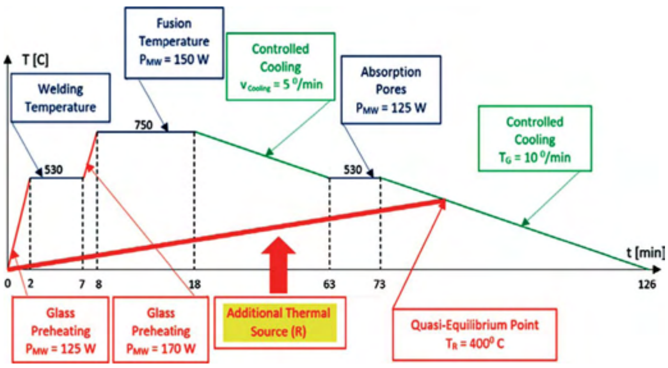

Figure 7. Heating-Cooling diagram using MW-R hybrid system.

The process is stable and the glasses can be welded if the heating-cooling diagram is applied to the joining process. The quality of the welds is not very good due to the massive flow of the glasses in the viscous state. This point is close to thermal runaway point and therefore the process can be unstable. By decreasing the temperature, the welding process cannot be obtained and by increasing the temperature, the danger of appearance of the thermal runaway phenomena is very high. Figure 9 presents the glasses welded using MW-R procedure.

Figure 8. Cracks of the glasses.

Figure 9. Glasses joined using hybrid MW-R procedure.

5. Conclusions

Glasses can be joined in microwave field if some conditions are met:

- The microwave field strength is enough to unlock the dipolar particles inside the materials and therefore to obtain the conversion of the microwave energy in heat
- By heating the glasses in microwave field, thermal runaway phenomena can occurs and the heating/cooling process is unstable. Therefore, an additional thermal sources for stabilizing the process is required. The second heating source will establish a thermal quasi-equilibrium of the samples during the cooling process.
- The MW-R joining process run only for effective welding process. The hybrid source is stopped when the samples temperature (on cooling) reach 400^0 C. From this point the only source which influences the process is the resistive source, the microwave generator being off.

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