MICROWAVE EFFECTS ON CFRP PROCESSING

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SUMMARY

Microwave heating of CFRP is a new method for CFRP processing that completely differs from conventional heating. As a result, the effects of the microwave heating on CFRP structures have to be explored. Hence, the development of a highly efficient, industrial microwave process for safe processing is the main objective. Microwave technology offers some typical characteristics for this purpose like instantaneous, volumetric and selective heating. Particular advantages are the reduction of processing time and increase in energy efficiency.
The effects of microwave heating are explored by considering epoxy systems like RTM6 and a carbon fiber fabric as an example. Tests performed on the resin show the influence of microwave preheating on the properties. The RTM6 resin has been tested using the DSC (Differential Scanning Calorimetrical) and rheological methods. The degree of the cure is almost equal to conventionally preheated RTM6 and the viscosity is reduced with microwave-heated batches.
Microwave-cured composites do not show any anomalous mechanical behavior.
The objective of proving the suitability of microwave processing for the manufacturing of composites has been achieved.

1. MICROWAVE BACKGROUND

The application of microwaves for the manufacture of CFRP is completely different from conventional heating methods and therefore represents a new manufacturing method. Microwave processes are used in different process steps in which heat is applied for further processing of the material. This process is used for heating resin, preforming and for curing composites. Microwave heating will replace conventional heating methods like convection ovens, heating sleeves or infrared units. The advantages of microwave technology are the selective and volumetric heating of the product. Selective means that only the product is heated and not the surrounding area, which saves energy.
Heating products in a microwave depends on several influencing factors. Moulding tools require an at least one-sided microwave transparency so that the microwaves can penetrate the product. The polar properties, which are characterized by the complex dielectricity number [1-4], are crucial for the material.

$$\varepsilon = \varepsilon' + i\varepsilon'' \qquad (1)$$

ε := complex dielectricity constants
ε' := real part (stored amount)
ε' := imaginary part (amount of loss)

Molecules that have a dipolar character are aligned in the alternating electrical field. Heat develops during the so-called polarization due to a loss of heat in the material. The dipoles in an alternating field are displaced of place. This phase displacement is described with the loss angle tanδ

$$\tan\delta = \frac{\varepsilon''}{\varepsilon'} \qquad (2)$$

The dielectric loss angle is the significant parameter for polymers to test their suitability for microwave heating.
Properties that are necessary to heat the material depend on influencing factors. For thermoset systems, viscosity, temperature and degree of polymerization are some of these factors. Alignment of the molecules is more feasible with declining viscosity than when in a solid condition so that, finally, the entire molecule is aligned in the direction of the alternating field since the dipoles are locally fixed on the molecule. The viscosity of the matrix system therefore also influences the dielectric loss and, with that, the complex dielectricity number. The effect described here is called a relaxation and describes the alignment time frame of individual dipoles. A complete relaxation is possible as long as the imaginary part of the dielectricity number reaches a maximum and the loss angle is maximized as well [1]. If a lossy dielectricum is exposed to an alternating field, the electromagnetic wave penetrates the dielectricum but is damped in the process. Energy is released and a term is defined for the performance difference ΔP [5,6].

$$\Delta P = P(1 - e^{-2ax}) \qquad (3)$$

a := damping constant
x := path in the field direction of the dielectricum

The damping constant a is given by:

$$a = \omega\sqrt{\frac{\mu'\varepsilon'}{2}\sqrt{(1+\frac{\chi^2}{\omega^2\varepsilon'^2})-1}} \qquad (4)$$

μ' := real part of the complex permeability
χ := conductive ability of the dielectricum

The conductive ability of the dielectricum results from the imaginary part of the complex dielectricity constants [6].

$$\chi = \omega\varepsilon_0 \cdot \varepsilon'' \qquad (5)$$

The depth of penetration in a dielectricum is relevant for the processing. The penetration depth is defined as the distance on which the performance difference ΔP was realized. It is also dependent on the wave length of the alternating electrical field λ_0 and shows that the depth of penetration increases with decreasing frequency but also that the released heat decreases in the dielectricum. The wave length of the microwave of 2.45 GHz is a good compromise [6].

$$\upsilon = \frac{\lambda_0}{2\pi\sqrt{\varepsilon''}\tan\delta} \qquad (6)$$

The penetration depth υ of the microwave in the product to be heated is a measure for an even distribution of the heat in relation to the wall thickness of the component. If a component has a greater wall thickness than the penetration depth of the microwave in the component material, the influence of the inner heat conduction in the component increases.

2. MICROWAVE APPLICATION

Additional boundary conditions occur particularly for injection processes when applying microwave heating. An injection process is divided into several process levels that are relevant for the microwaves since the fibers and matrix do not have the same dielectric properties. The fibers have to be heated to a certain temperature before the injection so that the resin front is not interrupted during the injection. The component consists of two different dielectric materials during the injection that must not only be protected from overheating but also from undercooling in order to guarantee an error-free injection. A possible risk in this process is that the component areas already impregnated with resin may be heated more than areas of the component that are still dry.
The boundary conditions of the different characteristics of dielectric properties have to be metrologically recorded since the quality-assured microwave process for the manufacture of CFRP components is a temperature-controlled process that requires temperature measurements at several measurement points.
The injection method for fiber-reinforced composite components is the state of the art for many components. The injection of a matrix system depends on its viscosity. The lower the viscosity, the easier it is to carry out an injection process and the duration of the injection is shorter as well. The viscosity of a matrix system depends on the temperature and degree of polymerization, whereby the degree of polymerization depends on the temperature and time.
For this reason, the injection resin is heated to a pre-defined temperature in preparation for the ensuing injection in order to obtain optimum properties with regard to the flow characteristics and processing time. The heating of individual resin containers greatly depends on the shape of the container. Batches ranging from 10 to 20 kg are common in aerospace applications. Heating those containers with today’s technology is very time consuming.
Due to the low inner heat conduction of epoxy resin the containers are stored in a preheated oven for up to four hours. It takes this long for the entire container to be heated adequately and evenly. It is hardly possible to shorten the process with current technology due to possible uncontrollable and exothermal reactions.

Still, the heating process needs to shortened in order to guarantee the availability of injectable resin and to provide a degree of flexibility in the production process. One way to shorten the heating process is by using microwaves. The dielectric properties of epoxy resins make them particularly suitable for being heated with microwaves. However, the suitability of each resin system for microwave heating must be determined by examining the material. Characteristic material parameters are examined to check influence of microwave heating on the material property of the matrix system. The remaining enthalpy, viscosity, shear strength and shear module are determined by the matrix. Material samples, which are cured under identical conditions, are manufactured for this purpose. The only difference in the samples is the pre-treatment of the matrix. One is conventionally heated in a convection oven for four hours and the other by microwaves for 25 minutes. The matrix systems of both are 80°C after heating. The following examination results were carried out for the resin system with the label RTM6 from the Hexcel company:

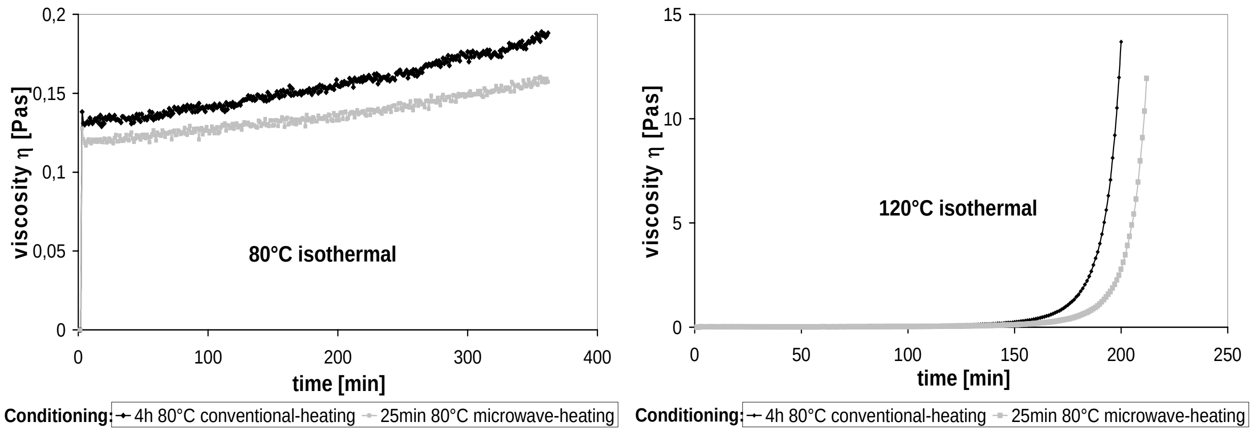

Table - 1 rheological comparison between conventionally and microwave-heated RTM6. (test temperature: 80°C and 120°C)

The rheological analysis of both cases clearly shows an uncritical influence of the microwaves on the viscosity. The viscosity of the matrix system should be reduced as much as possible for an injection that follows the heating of the resin. Due to the low increase in viscosity, RTM6 heated with microwaves is just as suitable for the injection process as conventionally heated RTM6.

In order to examine the influence on the degree of polymerization and remaining enthalpy, RTM6 pre-heated with microwaves and conventionally pre-heated RTM6 are cured at 180°C and then evaluated by means of a DSC analysis. Even here, no significant influence of the microwave heating on the RTM6 resin system can be determined.

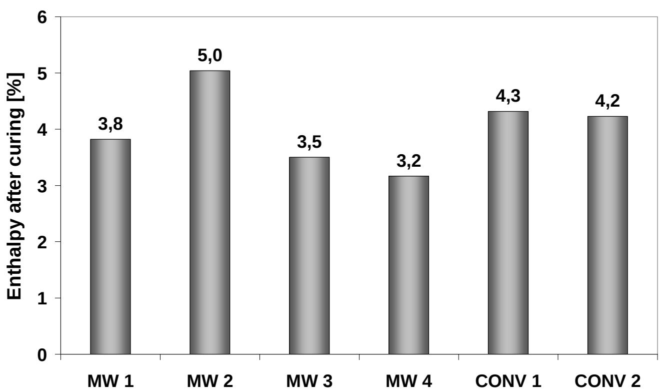

table - 2 DSC test for enthalpy on RTM6
MW microwave preheated to 80°C within 25min
CONV conventionally preheated to 80°C within 4h

In order to research the chemical bonding properties of the matrix on the carbon fiber, the shear properties of a composite component are examined according to a norm from Airbus: AITM 1.0002. The component is manufactured by using microwaves – the resin and a reference are heated with the current method. The components are cured under identical conditions. The results shown in table 3 show no direct influence of the microwave heating on the shear strength or on the shear module. No change can be determined in the structure of the matrix when examined by means of an infrared spectroscopy.

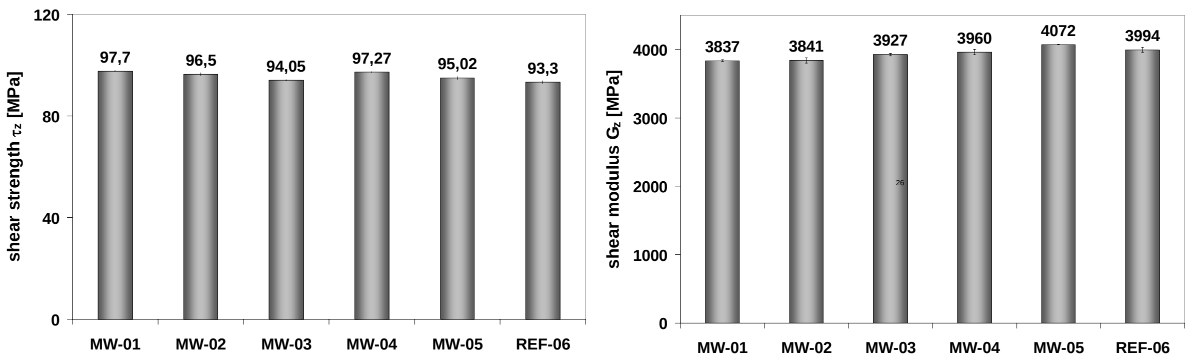

table - 3 shear characteristics for CFRP with RTM6 and a fibre volume content of 57%

The result for resin heated by microwaves is equivalent material properties at an approximately 90% reduction in processing time compared to current technology.
Since no changes occurred in the resin properties, a great potential for technical realizations can be seen here for further microwave processes like preforming and component curing. Preforming using the binder technology is also possible with microwave heating in order to minimize the effect of material-specific properties like poor heat conduction in preforms. Microwave preforms could be combined with the binder technology where the fiber materials and weaves are partially impregnated with a thermoset or thermoplastic polymer. The binder melts or connects by means of a thermal activation and stabilizes the preform.
Today, fiber plies are thermally activated by means of conventional heating methods like heating plates, hot air or infrared. However, the heat does not penetrate the product very effectively. The heating of the product is directly related to the temperature in the convection oven where the fibers and binder are passively heated. The oven atmosphere and mould must be heated, which is why only a small amount of the energy is applicable to the actual product. This is where the microwave technology comes in since microwaves heat the materials very selectively. Heating takes place only in the product to be heated and not in its surroundings.
This effect is also used when curing composite components. The bigger the product, the greater the potential for saving energy due to selective heating. The ratio of the component volume to the volume of an oven is very low for fiber-reinforced components in many applications. There is a great potential for the application of microwave heating to products used in the fiber composite industry.

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