Controlling the edge effect using a bypass conductor for induction welding of carbon fibre thermoplastic composites

Hagenbeek, Michiel; Vila Bramon, Kim; Fernandez Villegas, Irene

Publication date
2018

Document Version
Accepted author manuscript

Published in
Proceedings of the 18th European Conference on Composite Materials

Citation (APA)
Hagenbeek, M., Vila Bramon, K., & Fernandez Villegas, I. (2018). Controlling the edge effect using a bypass conductor for induction welding of carbon fibre thermoplastic composites. In *Proceedings of the 18th European Conference on Composite Materials: 24-28th June 2018, Athens, Greece*

CONTROLLING THE EDGE EFFECT USING A BYPASS CONDUCTOR FOR INDUCTION WELDING OF CARBON FIBRE THERMOPLASTIC COMPOSITES

M. Hagenbeek[1], J. Vilà Bramon[2] and I. Fernandez Villegas[3]

[1] Aerospace Engineering, Structural Integrity & Composites, Delft University of Technology, Kluyverweg 1, 2629 HS Delft, The Netherlands
Email: m.hagenbeek@tudelft.nl, Web Page: http://www.lr.tudelft.nl
[2]Aerospace Engineering, Structural Integrity & Composites, Delft University of Technology
Kluyverweg 1, 2629 HS Delft, The Netherlands
Email: j.vilabramon@tudelft.nl, Web Page: http://www.lr.tudelft.nl
[3]Aerospace Engineering, Structural Integrity & Composites, Delft University of Technology, Kluyverweg 1, 2629 HS Delft, The Netherlands
Email: i.fernandezvillegas@tudelft.nl, Web Page: http://www.lr.tudelft.nl

Keywords: Edge effect, induction welding, carbon fibre composites, electrical bypass

Abstract

Carbon fibre thermoplastic composites can be induction welded thanks to the electrical conductive nature of carbon fibre. Due to a locally contrained current flow more heat is generated at the edges of the composites. To counteract this so called edge effect a highly conductive material is attached to the edge to create an electrical bypass. The effect of a thin copper bypass has been assessed by performing induction heating experiments on single and double carbon fibre PPS composite coupons. The induction parameters where chosen such that without a bypass the edge would locally reach the melting temperature. The results clearly show the ability of the copper bypass to reduce the edge effect and prevent overheating at the edge.

1. Introduction

An important advantage of thermoplastic composites over thermoset composites is their ability to be welded. This enables process automation and reduction of assembling costs and explains the growing interest for thermoplastic composites in the aerospace and automotive industry [1,2]. Among the known fusion bonding techniques, one of the most promising is induction welding. Carbon fibre thermoplastic composites can be induction welded thanks to the electrical conductive nature of carbon fibre. In this process an alternating magnetic field results in induced currents, so called Eddy currents, in the carbon fibres. These currents generate heat which is dissipated in the material and enables the welding process.

One of the major challenges of induction welding is to overcome the undesirable edge effect. This effect appears when the coil is in the vicinity of the edge or when the dimensions of the coil are similar than the panel. The boundaries of the panel constrain the electrical paths and force the currents to flow along the edge. This causes a high current density near the edge which as a result is overheated [3]. There are several approaches to homogenise the heat generated in the composite. Pollack placed a metal part in the vicinity of the coil to partly shield the magnetic field [4]. Another option is to use a susceptor at the interface of the composite, for example a metal mesh [5-7]. The susceptor is very good electrical and magnetic conductor which generates the heat. The edge effect is then transferred from the composite panel to the susceptor and it is still diffcult to control the temperature. To reduce the edge effect the coil shape can be redesigned to generate a more locally confined magnetic field or the edges can be trimmed after welding the desired area. These solutions however increase manufacturing time and costs.

A novel approach is presented to counteract the intrinsic edge effect. In this approach a highly conductive material is attached to the edge to create an electrical bypass, see Figure 1. This redistributes the induced currents along the edge and a more uniform heat distribution is obtained. Both the electrical conductivity and the thickness of the bypass material play a role in reducing the edge temperature and thus preventing material degradation at the edge. When the bypass material has a thin thickness, h, the added area can be neglected and the total magnetic field is not affected. For a copper foil bypass an optimal thickness was found that avoids the overheating at the edge and brings back the temperature to the desired process window. The process was numerically modelled as well to gain deeper insight into the underlying physics of the edge effect and to optimise the bypass conductor. The numerical and experimental work established the ability of the proposed method to reduce the edge effect.

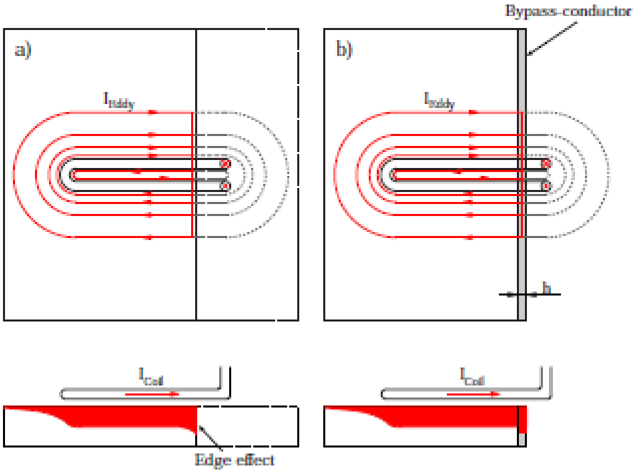

Figure 1 Schematic illustration of an induction heated composite coupon: a) without electrical bypass and b) with an electrical bypass at the right edge. Top view of the laminate and coil (top row) and side view (bottom row) with current density.

2. Experimental procedures

A 60 µm thick copper foil was chosen as the bypass material in the two different experiments described in this paper. In the first experiment a single carbon fibre PPS composite coupon was induction heated without and with a bypass at the edge. In the second experiment a small double coupon was induction heated up to the melting temperature of PPS. The left and right edge were placed at equal distance to the coil and a bypass was placed at one of the edges.

2.1 Single CF/PPS composite coupons without and with electrical bypass

The 90x90mm CF/PPS coupons consist of 6 plies of woven carbon fibre PPS semipreg with a $[0/90]_{3s}$ layup and a nominal thickness of 1.92mm. The coupons were cut from a 60x60cm panel after consolidation in a hot plates press for 2 hours at 320 °C and 10 bars pressure in accordance with the manufacturers guidelines. The coupon was placed on a wooden support with a hairpin induction coil underneath with a coupling distance of 4mm. The setup and exact coil position are shown in Figure 2.

The induction heating was performed with an actively cooled EasyHeat (Li) station from Ambrel Systems with a maximum power of 10kVA and a frequency range of 140-410kHz. An alternating coil current of 100A was used to heat up the coupon for 100s. The obtained resonance frequency was 375 kHz. The heating test was performed on a coupon without bypass (the reference) and a coupon with a 60µm thick copper bypass attached with kapton tape to the edge where the coil crosses the composite coupon. The test was numerically modelled in Comsol to gain insight in the current density.

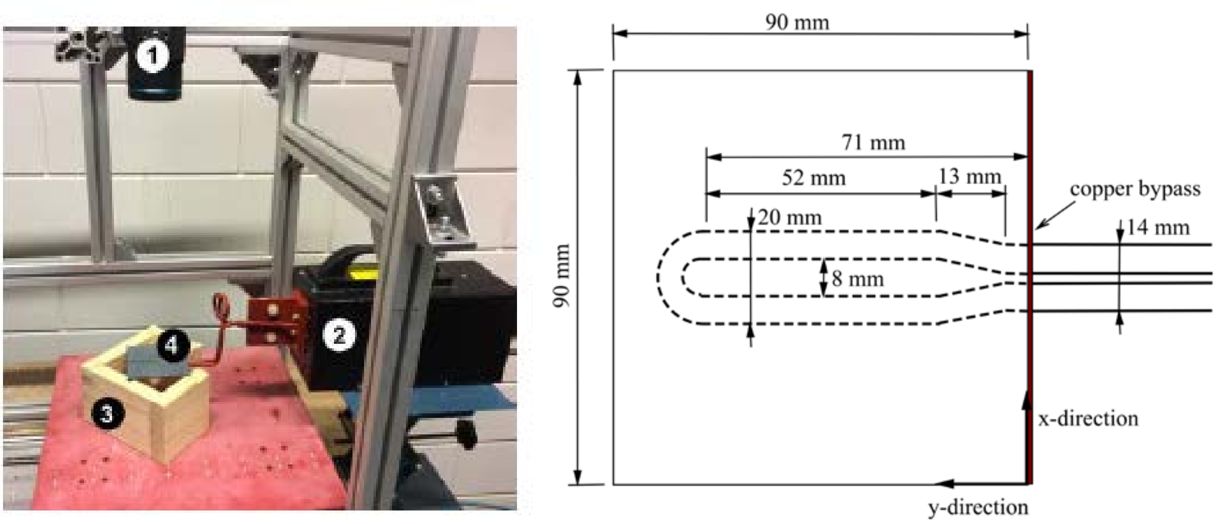

Figure 2 Left: experimental setup: (1) infrared camera, (2) hairpin coil and torch, (3) wooden support, (4) CF/PPS composite panel. Right: sketch of the coupon and hairpin coil dimensions and position.

2.2 Double CF/PPS composite coupons

In this induction heating test two composite coupons were placed on top of each other and positioned symmetrically under the hairpin coil, with a 7.4mm coupling distance. Thus, the edges at the left and right side of the composite coupons are both 10mm from the outer coil contour. The 40x100mm CF/PPS coupons consist of 4 plies of woven carbon fibre PPS semipreg with a $[0/90]_{2s}$ layup and a nominal thickness of 1.27mm. They were manufactured under the same conditions as the single composite coupons. In this case a coil current of 140A was used to heat up the coupons for 60s.

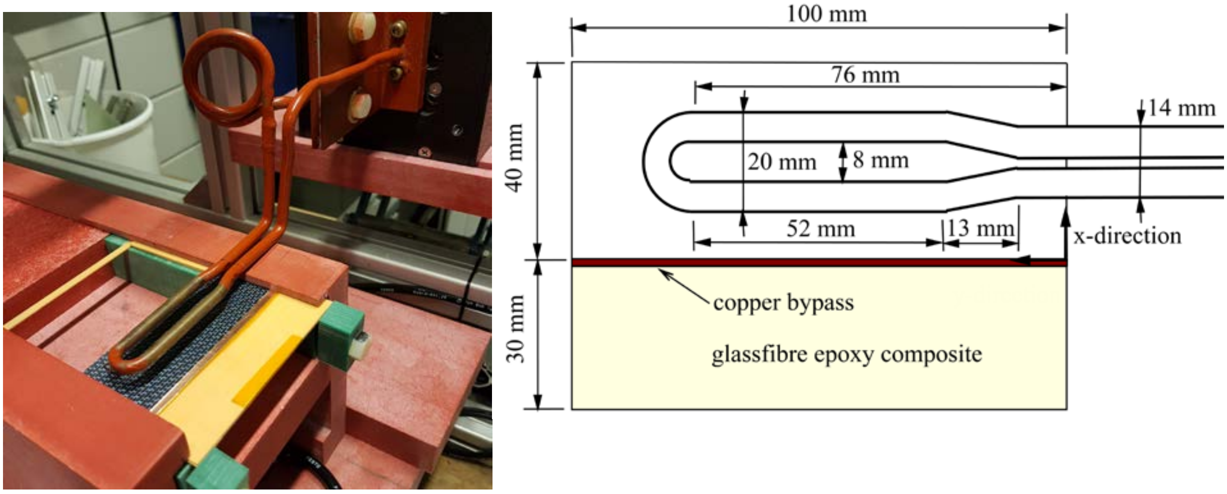

Figure 3 Two composite CF/PPS coupons on top of each other with a 60µm copper bypass clamped to the edges at the right side (by means of two glass-fibre epoxy coupons).

The obtained resonance frequency was 364 kHz. At the right side of the coupons, parallel to the coil, two 30mm wide glass-fibre epoxy composite coupons with a 60μm thick copper bypass were clamped to the edges. These coupons had a thickness of 1.25mm, comparable to the CF/PPS coupons. The temperature field was captured by an infrared thermal camera above the composite coupons. A similar test was performed to investigate the cooling effect of the two glass-fibre epoxy composite coupons without bypass.

3. Results and discussion

3.1 Single CF/PPS composite coupons

The numerical temperature distribution was found to be in good agreement with the experimentally obtained temperature field. Therefore, the numerical results are shown in Figure 4 below as the numerical model also yields the current density.

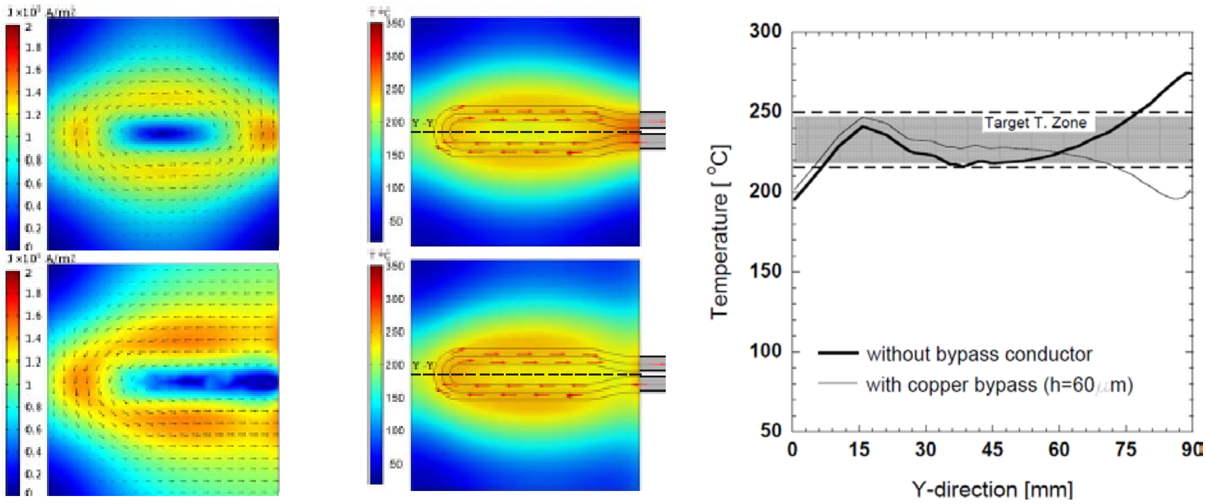

Figure 4 Numerical results for the current density (left), the temperature distribution for the reference and 60 μm thick copper bypass (centre), and the temperature profiles at the coupon centre line (right).

From these results the redistribution of currents in the composite coupon with the copper bypass can be clearly observed. The temperature right under the coil at the edge of the composite coupon is reduced with 73°C from 275 to 202°C. The experimental results showed with 22°C difference much less reduction of the peak temperature. This might be explained by a less perfect contact between the composite coupon and the copper bypass.

3.2 Double composite coupons

The results of the induction heating test on the double composite coupons is shown in Figure 5. The maximum temperature at the left edge (without bypass) was 278°C whereas the maximum temperature at the right edge (with copper bypass) reached only 215°C, a 63°C difference. The similar test with only the two glass-fibre epoxy composite coupons and without bypass showed a 8°C temperature difference between left and right edge. The more uniform temperature distribution is predominantly achieved by the redistribution of currents instead of improved heat transfer.

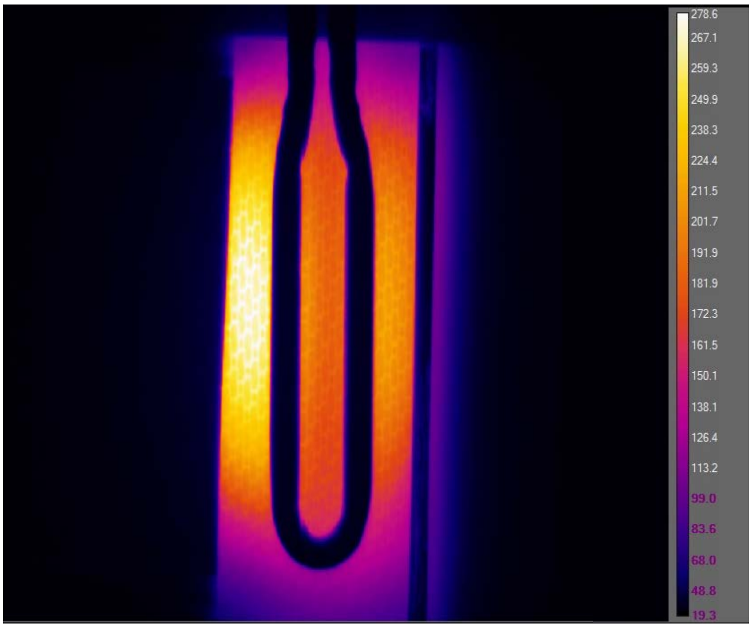

Figure 5 Infrared camera image of the top surface temperature distribution for the double composite coupons with a 60μm copper bypass clamped to the edges at the right side (by means of two glass-fibre epoxy coupons).

3. Conclusions

A novel method has been introduced to reduce the edge effect for induction welding composites. A highly conductive material, an electrical bypass, is thereby attached to the edge. The effect of a thin copper bypass has been assessed by performing induction experiments on single and on double composite coupons. The bypass mechanism alleviates the high current density at the edge and a more uniform temperature distribution is observed. The experiment with the double composite coupons showed a much larger reduction of the peak temperature at the edge than the single composite coupons (63°C versus 22°C). This is explained by the improved contact between the bypass and the composite edge by applying pressure. The results clearly show the ability of the copper bypass to reduce the edge effect and prevent overheating at the edge.

Acknowledgments

The experimental support and advice of Frans Oostrum, technician in the Delft Aerospace Structures & Materials Laboratory, is gratefully acknowledged. The presented work has been filed in a patent application with reference number 017139 NL-PD.

References

[1] C. Ageorges, L. Ye, and M. Hou. Advances in fusion bonding techniques for joining thermoplastic matrix composites: a review. *Composites Part A:Applied Science and Manufacturing*, 32(6):839-857, 2001.

[2] P. Mitschang, R. Rudolf, and M. Neitzel. Continuous induction welding process, modelling and realisation. *Journal of Thermoplastic Composite Materials*, 15(2):127-153, 2002.

[3] T. Ahmed, D. Stavrov, H. Bersee, and A. Beukers. Induction welding of thermoplastic composites an overview. *Composites Part A: Applied Science and Manufacturing*, 37(10):1638-1651, 2006.

[4] Z. Pollack and B. Svard. Device for induction welding, Feb. 18 1986. URL http://www.google.com/patents/US4571472. US Patent 4,571,472.

[5] S. Yarlagadda, B. Fink, and J. Gillespie. Resistive susceptor design for uniform heating during induction bonding of composites. *Journal of Thermoplastic Composite Materials*, 11(4):321–337, 1998.

[6] K. Hansen and C. Lunden. Tailored susceptors for induction welding of thermoplastic, March 19 1996. URL https://www.google.com.au/patents/US5500511. US Patent 5,500,511.

[7] K. Hansen and E. Weisberg. Selvaged susceptor for thermoplastic welding by induction heating, April 16 1996. URL https://www.google.com.au/patents/US5508496. US Patent 5,508,496.