Adhesive Joining of Structural Components

New Insights and Technologies

An SAE Technical Paper Compilation

Edited by Alessandro Pegoretti

Adhesive Joining of Structural Components: New Insights and Technologies

Adhesive Joining of Structural Components: New Insights and Technologies

Warrendale, Pennsylvania, USA

400 Commonwealth Drive
Warrendale, PA 15096-0001 USA
E-mail: CustomerService@sae.org
Phone: 877-606-7323 (inside USA and Canada)
724-776-4970 (outside USA)
Fax: 724-776-0790

Copyright © 2019 SAE International. All rights reserved.

No part of this publication may be reproduced, stored in a retrieval system, distributed, or transmitted, in any form or by any means without the prior written permission of SAE International. For permission and licensing requests, contact SAE Permissions, 400 Commonwealth Drive, Warrendale, PA 15096-0001 USA; e-mail: copyright@sae.org; phone: 724-772-4028; fax: 724-772-9765.

Library of Congress Catalog Number 2018940857

SAE Order Number PT-191

<http://dx.doi.org/10.4271/PT-191>

Information contained in this work has been obtained by SAE International from sources believed to be reliable. However, neither SAE International nor its authors guarantee the accuracy or completeness of any information published herein and neither SAE International nor its authors shall be responsible for any errors, omissions, or damages arising out of use of this information. This work is published with the understanding that SAE International and its authors are supplying information, but are not attempting to render engineering or other professional services. If such services are required, the assistance of an appropriate professional should be sought.

ISBN-Print 978-0-7680-9287-5

ISBN-PDF 978-0-7680-9537-1

ISBN-ePUB 978-0-7680-9289-9

ISBN-PRC 978-0-7680-9290-5

ISBN-HTML 978-0-7680-9288-2

To purchase bulk quantities, please contact: SAE Customer Service

E-mail: CustomerService@sae.org
Phone: 877-606-7323 (inside USA and Canada)
724-776-4970 (outside USA)
Fax: 724-776-0790

Visit the SAE International Bookstore at books.sae.org

contents

Introduction	<u>xi</u>
--------------	-----------

CHAPTER 1

Influence of Ductility Ingredients of Structural Adhesives on Fracture Energy under Static Mixed-Mode Loading	<u>1</u>
Introduction	<u>2</u>
Fracture Energy Values in Adhesives	<u>2</u>
Methods for the Evaluation of Adhesives in Mixed-Mode Loading Conditions	<u>3</u>
Experimental Procedure	<u>4</u>
Adhesive Property	<u>4</u>
DCB Specimen	<u>4</u>
Data Reduction Scheme (Compliance-Based Beam Method)	<u>5</u>
Mixed-Mode Tests Procedure	<u>7</u>
Test Result	<u>9</u>
Double-Cantilever Beam (DCB) Test	<u>9</u>
End Notched Flexure (ENF) Test	<u>9</u>
Mixed-Mode Test	<u>10</u>
Fracture Envelopes	<u>15</u>
Fracture Surface of Adhesives	<u>16</u>
Conclusions	<u>16</u>
References	<u>17</u>
Contact Information	<u>18</u>
Acknowledgments	<u>18</u>
Nomenclature	<u>18</u>

CHAPTER 2

Surface Pretreatment Effect on the Adhesively Single Lap Joint of 6061-T6 Aluminum Alloy and Carbon Fiber T-700/Epoxy Composites	<u>21</u>
Introduction	<u>21</u>
Test Setup	<u>22</u>
Materials and Joint Configuration	<u>22</u>
Surface Treatments	<u>23</u>

Surface Roughness Measurements	<u>23</u>
Shear Test	<u>24</u>
Image Analysis of Surface Roughness Readings	<u>26</u>
Post-Failure Fracture Analysis	<u>26</u>
Summary/Conclusions	<u>27</u>
References	<u>28</u>
Contact Information	<u>29</u>
Acknowledgments	<u>29</u>

CHAPTER 3

Emerging Technologies for Use in Aerospace Bonded Assemblies	<u>31</u>
Introduction	<u>32</u>
Surface Energy Measurement	<u>33</u>
Equipment and Method	<u>33</u>
Equilibrium Time	<u>33</u>
Fluid Type, Surface Finish, and Variability	<u>33</u>
Contaminants	<u>34</u>
Application in Aerospace Production	<u>34</u>
Surface Treatment	<u>35</u>
Equipment and Method	<u>35</u>
Surface Temperature	<u>36</u>
Surface Energy and Cleaning	<u>36</u>
Application in Aerospace Production	<u>36</u>
FTIR Characterization	<u>37</u>
Method	<u>37</u>
Contaminant Results	<u>37</u>
Epoxy Resin Mix Ratio	<u>38</u>
Application in Aerospace Production	<u>39</u>
Adhesive Mixing	<u>40</u>
Summary/Conclusions	<u>40</u>
References	<u>41</u>
Contact Information	<u>41</u>

CHAPTER 4

Innovative Production Technologies for Large Components	<u>43</u>
Introduction	<u>43</u>
IProGro	<u>44</u>
Approach	<u>44</u>
Surface Treatment	<u>44</u>
Inspection Systems	<u>45</u>

Reconfigurable Fixture	45
Assistance Systems	46
Demonstration Area	46
Setup	46
Human-Robot Collaboration	46
Work Cycle	47
Summary/Conclusions	47
Contact Information	48
Acknowledgments	49
Definitions/Abbreviations	49

CHAPTER 5

Numerical Investigation of the Rivet Installation in an Adhesively Bonded Joint and the Load Transfer in a Bolted/Bonded Hybrid Joint 51

Introduction	52
Rivet Installation in an Adhesively Bonded Joint	53
Rivet Installation Model	53
Element Type and Mesh Section	53
Material Model	53
Boundary and Contact Conditions	53
Experimental Validation	54
Experimental Equipment	54
Rivet Installation Model without a Bondline	54
<i>Force-Displacement</i>	54
<i>Geometrical Characteristics of Formed Rivet Head</i>	54
Rivet Installation Model with a Bondline	55
<i>Change of the Bondline Thickness after the Rivet Installation in An Adhesively Bonded Joint</i>	55
Parametric Study	55
Parametric Study for the Rivet Installation in an Adhesively Bonded Joint	55
<i>Residual Stress Distribution</i>	56
<i>Contact Force</i>	56
Load Transfer in a Bonded/Bolted Hybrid Joint	60
Lap Joint Simulation Model	61
Experimental Validation	61
Effect of the Rivet Installation on a Bonded/Bolted Hybrid Joint	62
Load Transfer Parametric Study	62
Bondline Shear Stress in a Bonded/Bolted Hybrid Joint	63
Load Transfer in a Bonded/Bolted Hybrid Joint	63
Summary and Conclusion	64
References	65
Contact Information	66

CHAPTER 6

Cracking Stopping in the Bondline of Adhesively Bonded Composite Adherents by Means of a Mechanical Fastener: Numerical and Experimental Investigation	<u>67</u>
Introduction	<u>68</u>
Influence of Mechanical Fastener on the Bondline Short-Term Cracking Behavior of Adhesively Bonded Composite Structure	<u>69</u>
Configuration of the CLS Specimen	<u>69</u>
Simulation Model	<u>69</u>
Experimental Validation of the Simulation Model	<u>70</u>
The Adherents' Strain	<u>70</u>
Joint Stiffness, Joint Strength, and the Crack Front	<u>70</u>
Crack Length-Force Curve	<u>71</u>
Crack Propagation in an Adhesively Bonded Joint and the Influence of the DSF	<u>71</u>
Cracking Stopping Mechanisms	<u>72</u>
Adhesive's Influence on the DSF Cracking Stopper Potential	<u>73</u>
Influence of the DSF on the Long-Term Bondline Cracking of an Adhesively Bonded Joint	<u>74</u>
Summary and Conclusion	<u>74</u>
Contact Information	<u>75</u>
References	<u>75</u>

CHAPTER 7

Testing of Adhesive Bonds on Large Industrial Components Made of CFRP with a Robot Inspection System Using Active Thermography, Leading to Reduced Cycle Times	<u>77</u>
Introduction	<u>78</u>
Thermal Sensors	<u>78</u>
Thermal Resolution	<u>79</u>
Geometric Resolution	<u>79</u>
Temporal Resolution	<u>79</u>
Active Thermography	<u>79</u>
Pulsed Thermography	<u>79</u>
Lock-In Thermography	<u>80</u>
Pulsed-Phase Thermography	<u>80</u>
Thermographic Inspection with Continuous Movement Specimens	<u>80</u>
Parameter Setting of the Continuous Inspection	<u>81</u>
Automatic Detection of Defects	<u>81</u>

Summary/Conclusions	<u>82</u>
References	<u>82</u>
Contact Information	<u>82</u>
Acknowledgments	<u>83</u>

CHAPTER 8

Extended Non-Destructive Testing of Composite Bonds 85

Introduction	<u>86</u>
Body	<u>87</u>
Aerosol Wetting Technique	<u>87</u>
Laser Adhesion Test: LASAT	<u>89</u>
Summary/Conclusions	<u>90</u>
References	<u>91</u>
Contact Information	<u>92</u>
Acknowledgments	<u>93</u>
Definitions/Abbreviations	<u>93</u>

CHAPTER 9

Failure Modeling of Adhesive Bonded Joints with Cohesive Elements 95

Introduction	<u>95</u>
Quasistatic Tests and Fatigue Tests	<u>96</u>
Modeling of Adhesive Failure	<u>97</u>
Simulations and Results	<u>98</u>
Conclusions	<u>100</u>
Next Steps	<u>101</u>
References	<u>101</u>
Contact Information	<u>101</u>
Acknowledgments	<u>101</u>

CHAPTER 10

Prediction of the Behaviors of Adhesively Bonded Steel Hat Section Components under Axial Impact Loading 103

Introduction	<u>104</u>
Materials	<u>105</u>
Finite Element Modeling of Adhesively Bonded Joints	<u>105</u>
Single Lap Shear Joint	<u>106</u>
T-Peel Joint	<u>107</u>

Impact Simulation of Spot-Welded Steel Hat Sections	<u>107</u>
Impact Simulation of Adhesively Bonded Steel Hat Sections	<u>109</u>
Summary/Conclusions	<u>110</u>
References	<u>110</u>
Contact Information	<u>111</u>
About the Author	<u>113</u>