PDL HANDBOOK SERIES

Handbook of Plastics Joining

A Practical Guide, Second Edition

Edited by
Michael J. Troughton

TWI

pdl
Plastics Design Library

INTEX EX. 1046, Pg. 1
Intex Recreation v. Bestway Inflatables, IPR2023-00488

HANDBOOK OF PLASTICS JOINING

A Practical Guide

Second Edition

Edited by
Michael J. Troughton

The Welding Institute, Cambridge, UK

Norwich, NY, USA

INTEX EX. 1046, Pg. 2
Intex Recreation v. Bestway Inflatables, IPR2023-00488

Copyright © 2008 by William Andrew Inc.
No part of this book may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying, recording, or by any information storage and retrieval system, without permission in writing from the Publisher.

ISBN: 978-0-8155-1581-4

Library of Congress Cataloging-in-Publication Data

Troughton, M. J.
Handbook of plastics joining : a practical guide / M.J. Troughton. -- 2nd ed.
p. cm.
Includes bibliographical references.
ISBN 978-0-8155-1581-4
1. Plastics--Welding--Handbooks, manuals, etc. I. Title.
TP1160.T76 2008
668.4--dc22

2008007369

Printed in the United States of America

This book is printed on acid-free paper.

10 9 8 7 6 5 4 3 2 1

Published by:
William Andrew Inc.
13 Eaton Avenue
Norwich, NY 13815
1-800-932-7045
www.williamandrew.com

ENVIRONMENTALLY FRIENDLY
This book has been printed digitally because this process does not use any plates, ink, chemicals, or press solutions that are harmful to the environment. The paper used in this book has a 30% recycled content.

NOTICE
To the best of our knowledge the information in this publication is accurate; however the Publisher does not assume any responsibility or liability for the accuracy or completeness of, or consequences arising from, such information. This book is intended for informational purposes only. Mention of trade names or commercial products does not constitute endorsement or recommendation for their use by the Publisher. Final determination of the suitability of any information or product for any use, and the manner of that use, is the sole responsibility of the user. Anyone intending to rely upon any recommendation of materials or procedures mentioned in this publication should be independently satisfied as to such suitability, and must meet all applicable safety and health standards.

5 Radio Frequency Welding

5.1 Process Description

Radio frequency (RF) welding, also called high frequency welding, HF welding or dielectric welding, uses high frequency (normally 27.12 MHz) electromagnetic energy to generate heat in materials by virtue of their electrical properties; the material to be welded must be able to convert the alternating electric field into heat. Polar molecules in an electric field tend to orient in the field direction so that the positive (or negative) end of the dipole aligns to the negative (or positive) charges in the electric field. This process is called dipole polarization. Nonpolar molecules in an electric field displace electron clouds to align with the field (electronic polarization), so that centers of positive and negative charges no longer coincide. Electronic polarization is instantaneous and does not result in heat generation. Dipolar polarization, however, is not instantaneous at the high frequencies used in RF welding; as the dipoles try to align with the rapidly alternating electric field, orientation becomes out-of-phase. The imperfect alignment causes internal molecular friction and results in the generation of heat.

The delay between changes in electric field direction and changes in dipolar polarization is shown in Fig. 5.1. An oscillating electric field E generates an oscillating current I within the polar material. At high frequencies, the two curves are out of phase by the phase angle θ; the loss angle is defined as $90 - \theta$ or δ. The amount of energy absorbed per cycle from the electric field is represented by the power factor and the dissipation factor; the power factor is defined as $\cos \theta$, and the dissipation factor or loss tangent is $\tan \delta$, a ratio of current dissipated into heat to current transmitted. The amount of dipole polarization is dependent on frequency and temperature. At low frequencies, the power lost by the electric field is low due to dipole alignment with the electric field. At high frequencies, field reversal is so rapid that dipole alignment becomes out of phase, and power losses increase. Eventually, a maximum in power loss is reached, so that further frequency increases result in decreased power loss. Dipole polarization is low at low temperatures but increases with increasing temperature [1].

Typically, an RF welding machine has two platens—an upper, moveable one and a lower, fixed one, also called a bed. The upper platen is connected to the RF generator, whilst the lower platen is connected to electrical earth. Tooling, known as the electrode or welding rule, is attached to the upper or lower platen and defines the shape and dimensions of the weld.

The parts to be welded are placed between the platens and a press then lowers the upper platen so that a preset amount of pressure is applied to the joint area. Once the parts are clamped, the RF energy is applied for a preset time, called the heating time. Once the heating time has elapsed, the electrodes continue to clamp the parts until the weld solidifies. This is called the hold or cooling time. The press then opens and releases the welded assembly.

RF welding is normally only used for joining films and thin sheets. This is because a sufficiently strong electric field to produce material melting can only be achieved when the gap between the electrode and the opposing platen is less than around 1.5 mm (0.06 inches).

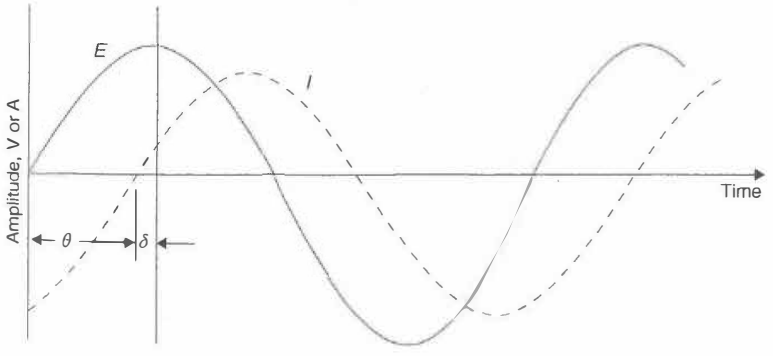

Figure 5.1. Electrical representation of dipole polarization resulting in heat generation due to imperfect alignment.

INTEX EX. 1046, Pg. 4
Intex Recreation v. Bestway Inflatables, IPR2023-00488

dielectric constant, superior chemical resistance, very high thermal stability, low friction coefficient, excellent antiadhesive properties, low flammability, and high weatherability. Impact resistance of PTFE is high, but permeability is also high whereas strength and creep resistance are relatively low. The very high melt viscosity of PTFE restricts its processing to sinter molding and powder coating. Uses include coatings for cooking utensils, chemical apparatus, electrical and nonstick items, bearings, containers. Also, PTFE spheres are used as fillers and PTFE oil is used as a lubricant in various plastics. Also called PTFE, TFE.

polytetramethyleneadipamide—See *nylon 46*.

polytetramethylene terephthalate—See *polybutylene terephthalate*.

polythiophenylene—See *polyphenylene sulfide*.

polyurethane—A large class of polymers, the backbone of which consists of repeating units containing urethane group. PUs are usually prepared by interfacial polycondensation of polyisocyanates with polyols. The latter may be based on polyesters or polyethers or both. The most important members of this class are urethane rubbers, nonelastomeric thermoplastic PUs, urethane thermoplastic elastomers , and thermoset urethane resins. PUs may be rigid or soft and flexible, cellular or solid and offer a wide range of properties depending on composition and molecular structure. In general they have high abrasion resistance, good retention of properties at low temperatures, and good foamability, but poor heat resistance, weatherability, and resistance to solvents. PUs are flammable and are made with toxic substances (isocyanates). Nonelastomeric thermoplastic PUs are not chemically crosslinked and are processed by injection molding and extrusion. Thermoset PUs can be cured at moderate and ambient temperatures and give foams with good heat insulating properties. They are processed mainly by reaction injection molding, various foam techniques, casting, and coating. PUs are used in load bearing rollers and wheels, acoustic damping materials, sporting goods, seals and gaskets, rigid and flexible foams for heat insulation and other uses, potting, and encapsulation. Also called PU, urethane polymer. See also *nonelastomeric thermoplastic polyurethane, nonelastomeric thermosetting polyurethane, urethane thermoplastic elastomer*.

polyurethane adhesive—One- or two-part adhesives that cure by a polymerization reaction to form temperature resistant bonds that are both rigid and flexible.

polyurethane thermoplastic rubber—See *urethane thermoplastic elastomer*.

polyurethane TPE—See *urethane thermoplastic elastomer*.

polyvinyl chloride—A thermoplastic prepared by free-radical polymerization of vinyl chloride in dispersion (emulsion), bulk, or suspension processes. A small amount of comonomer is sometimes added to enhance adhesion or other properties. Unmodified PVC is rigid and requires plasticizers to make it more flexible. The main end forms of PVC are rigid and flexible. The flexible form is often made from plastisols, suspensions of PVC in liquid plasticizers. PVC can be chlorinated to increase its heat deflection temperature and tensile strength and to reduce flammability and smoke generation. PVC is dimensionally stable, largely nonflammable, and resistant to weathering, but has limited thermal stability, high density, and is attacked by many solvents. Processed by injection molding, calandering, extrusion, powder coating, blow molding, extrusion coating, and film techniques. Used very widely as films, fabric coatings, wire coatings, toys, bottles, and pipes. Also called PVC. See also *unplasticized polyvinyl chloride*.

polyvinyl dichloride—See *polyvinylidene chloride*.

polyvinyl fluoride—A highly crystalline material with high toughness, high flexibility, outstanding weathering resistance, and good abrasion resistance. Commercially available only as a film. Useful properties are maintained over a temperature range of –94°F (–70°C) to 230°F (110°C). Used for packaging, glazing, and electrical applications. Also called PVF.

polyvinylidene chloride—A stereoregular, thermoplastic polymer derived by the polymerization of vinylidene chloride or copolymerization of vinylidene chloride with lesser amounts of other unsaturated compounds. This polymer is resistant to abrasion and chemical attack, impermeable to flavor, and possesses low vapor transmission properties. Uses include packaging for food, insecticide-impregnated multiwall paper bags, pipes for chemical processing equipment, seat covers, upholstery, fibers, bristles, and latex coatings. Also called polyvinyl dichloride, PVDC.

polyvinylidene fluoride—Thermoplastic prepared from vinylidene fluoride. It has substantially higher strength, wear resistance, and creep resistance than other fluoropolymers but relatively high dielectric constant and loss factor. PVDF is nonflammable, resists most solvents, and has excellent weatherability. Its service temperature limit

INTEX EX. 1046, Pg. 5
Intex Recreation v. Bestway Inflatables, IPR2023-00488