ADHESION OF POLYMER COATED STEEL WIRE BY COMPRESSION MOLDING AND EXTRUSION PROCESS

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To

My Beloved Family

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ABSTRACT

Steel wires coated with thermoplastics have found a wider range of application in the field of science and engineering. However, steel-polymer interfaces frequently suffer from poor adhesion strength that is undermining their long-term stability under external stress because of weak interaction between the steel and polymer surfaces. Therefore, the present study aims to investigate the influence of adhesive (Chemlok 213 and Cilbond 49SF) on the adhesion strength of galvanized and ungalvanized steel wire coating with thermoplastic polyurethane (TPU). Surface treatments including grinding with sandpaper, thermal oxidation and degreasing with alkaline solution were done on the steel wire substrate prior to coating by compression molding and extrusion process. The adhesion was characterized with a single wire pullout test and field emission scanning microscopy (FESEM). The experimental results confirmed that Cilbond 49SF adhesive with sandpaper grinding treated wire outperformed all other surface treatments tested. In comparison of the processes, compression molding process has an upper hand over the extrusion process because it provide an avenue for sufficient control of curing time required for optimum setting of the adhesive.

ABSTRAK

Wayar keluli yang disalut dengan thermoplastics telah menemui pelbagai jenis aplikasi dalam bidang sains dan Kejuruteraan. Walau bagaimanapun, antara muka keluli-polimer sering menderita daripada kekuatan rekatan miskin yang melemahkan kestabilan jangka panjang mereka di bawah tekanan luar kerana interaksi lemah antara permukaan keluli dan polimer. Oleh itu, kini kajian bertujuan untuk menyiasat pengaruh pelekat (Chemlok 213 dan Cilbond 49SF) kekuatan lekatan salutan dawai keluli tergalvani dan ungalvanized dengan termoplastik poliuretana (TPU). Rawatan permukaan termasuk pengisaran dengan kertas pasir, pengoksidaan terma dan sektor penyahgris dengan alkali penyelesaian yang dilakukan pada substrat dawai keluli sebelum salutan oleh proses membentuk dan penyemperitan mampatan. Lekatan itu yang disifatkan dengan ujian pullout tunggal wayar dan Field Emission Scanning Microscopy (FESEM). Keputusan eksperimen mengesahkan bahawa Cilbond 49SF pelekat dengan kertas pasir pengisaran dawai dirawat sejak lain rawatan permukaan yang diuji. Perbandingan proses, mencetak proses mampatan mempunyai satu atas tangan ke atas proses penyemperitan kerana ia memberi peluang untuk kawalan mencukupi pengawetan masa yang diperlukan untuk seting optimum pelekat.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Polymer coating is receiving increasing attention from both the researchers and industries as they offer an attractive low-cost substitute to the development of entirely new materials. Polymer coating of metal wire is done for the purpose of electrical insulation and corrosion protection, as well as the need to provide a superior surface for lubrication and to facilitate bonding to other structural media. Moreover, steel-cords reinforced thermoplastic composites are recyclable and use cost efficient raw materials (Golaz et al., 2011). Steel reinforced thermoplastic have found applications in the rehabilitation or upgrading of bridges and concrete buildings, in pressurized pipelines and in tires technology. Kamal (2013) added other areas of steel coated wire application which include the cable industry, offshore application and for transmission belts. While it is also possible to achieve the mechanical properties by using lightweight ultra-high strength wire as we know in the market now, there is a pending struggle of strength to weight ratio (Banfield and Casey, 1998). Polymer coatings give a better balance between cable weight reduction and greater cable flexibility (Lamb and Hashmi, 1991).

Enhancing the adhesion properties of solid interfaces between metals and polymeric materials is one of the most important issues in materials science because high adhesion strength of interfaces is essential to realizing their practical applications in film or paint coatings, joints, automobiles, aircraft, semiconductors, data-storage devices, thin-film transistors, and flexible electronics (Yacobi et al., 2002; Amancio-Filho and Dos Santos, 2009; Pocius, 2012).

In particular, adhesion between steel and polymer composites is very important because steel is mechanically stronger than other metals and is widely used in the mechanical and microelectronics industries (Yacobi et al., 2002). Adhesives such as epoxy, acrylate, and cyanoacrylate are commonly used in industries (Yun et al., 2011). However, steel-polymer interfaces frequently suffer from poor adhesion strength, undermining their long-term stability under external stress because of weak interactions between the steel and polymer surfaces.

Recent years in the world have seen the development of a variety of new epoxy resins, where BPA is no longer a constituent (Yun et al., 2011). One of the more interesting scientific solutions to the problem is the development of epoxy resins from Schiff bases (Langer et al., 2014). The presence of the –CH=N-Ar azomethine group in a resin macromolecule improves adhesion of the coating to a metal substrate and increases its thermal stability. In addition, Schiff bases constitute good corrosion inhibitors and are good passivation agents for steel, copper and aluminium (Atta et al., 2006b; Mija et al., 1996; Atta et al., 2006a). Epoxy resins which contain in their structure a complex metal ion have better thermal stability and very good mechanical properties while maintaining low processing temperatures (Atta et al., 2006a; Langer et al., 2014).

There are different approaches to modify epoxy resins to improve these shortcomings and maintain those properties that have been proven desirable. There are various ways to achieve this: Choi et al. (2004) recommended introduction of substituents into the mesogenic units, this recommendation conform with the earlier submission of Ribera et al. (2003). Introduction of a flexibility spacer, decouples the reactive end-functional group from the rigidrod mesogenic group (Castell et al., 2004). However, Giamberini et al. (1997) insist on altering the curing reaction of rigid-rod mesogenic epoxy monomers with aliphatic dicarboxylic acids. Polymer products manufacturers and parts producers took advantage of the research on various adhesive modifications to produce adhesive products with improved thermal stability and a very good mechanical property while maintaining low processing temperatures.

Not all polymeric materials are compatible for bonding with steel wire, using High Density Poly-Ethylene (HDPE) coated on metal (Xie et al., 2008). He further declared that it gives a strong composite material that provides an excellent tensile strength, highly abrasion-resistant and is unaffected by acidity or alkalinity. Lamb and Hashmi (1991) worked on polymer coating of superfine wire, describing it as a lightweight wire rod that resists aggressive chemicals, withstands freeze-thaw cycles and continuous subzero temperatures without cracking. Golaz et al. (2011) recommended thermoplastic polyurethane for coating on galvanized steel. Low-cost processing of polymer composite materials can be done by compression molding, extrusion or hot press machine. Martyn et al. (2009) thought that co-extrusion may be used successfully to apply a polymer coating onto the wire with better bonding between the coating and the rope by studying the mechanism of interface formation and adhesion behavior.

Nevertheless, bonding and joining between polymer and steel is an important issue because thermoplastic are highly un-reactive materials with a low polarity and therefore, cannot adhere on steel wire. It is thus necessary to change the interface properties to promote adhesion. This can be achieved by chemical modification of bulk polymer material, by physio-chemical modification of one or both constituents of the interface, and/or by the use of coupling agents (adhesives) that are chemically reactive with both polymeric material and metal (Lu et al., 2005a; Golaz et al., 2011). In view of this background this study is to examine the effect of some commercial adhesives on the adhesion of polymer coated steel wire rope by extrusion process and compression molding.

1.2 Problem Statement

The use of polymer coatings depends strongly on their service conditions and the chemical or physical bonding properties of the composite. Polymer coated steel wires are currently in applications in tire technology, the cable industry, offshore application and for transmission belts. Hence (Golaz et al., 2013) and (Kamal, 2013) deduced that bonding and joining between polymer and steel is an important issue because most plastics are highly un-reactive materials with a low polarity and therefore, cannot adhere on steel wire. Poor adhesion can be caused by many factors such as mismatch of adhesive material used between the polymer and the metal substrate, impurities and in appropriate surface which failed to initiate the required bonding mechanism etc.

Beside adhesion, the appropriate processing method to use is an important factor which influences the adhesive bond of polymer coating on steel wire. Therefore, this study will focus on promoting the adhesion of thermoplastic Polyurethane (TPU) on steel wire by identifiying the effective adhesive material for TPU polymer coating of steel wire by compression molding and extrusion process.

1.3 Objectives

1. To study the effect of adhesive material for TPU polymer coating of steel wire by compression molding and extrusion process.

2. To conduct a single wire pull-out test for adhesion properties of TPU polymer-steel wire cord.

1.4 Scope of Research

1. Prepare the polymer coated steel wire by compression molding and extrusion process with and without adhesive materials.

2. Conduct surface treatment and modifications to better adhesion of TPU polymer to steel wire.

3. Conduct a pull-out adhesion test and microstructure analysis for the samples prepared.

1.5 Research Output

The expectation of the study is to produce a polymer coated steel wire rope with a good adhesion for excellent strength and toughness that can yield a high resistance to oil and water.

1.6 Contribution

Polymer coated steel wire rope have found applications in the rehabilitation or upgrading of bridges and concrete buildings. With evidence from the rehabilitation of the Maryland Bridge in Lagos and the construction of the second Niger bridge all in Nigeria, as well as the construction of second bridge of Penang Malaysia. Steel wires reinforced polymeric composites are currently in applications in tires technology, in the cable industry, offshore application and for transmission belts**.** This study is to improve more on the application of polymer (Thermoplastic Polyurethane) coated steel wire rope in offshore application, which will all together help the offshore industries such as oil and gas, which are the larger contributors to the economy of Nigeria and Malaysia.

REFERENCES

Amancio-Filho, S. and Dos Santos, J. (2009). Joining of polymers and polymer-metal hybrid structures: Recent developments and trends. *Polymer Engineering and Science.* 49(8)**,** 1461.

Amornsakchai, T. and Doaddara, O. (2008). Grafting of acrylamide and acrylic acid onto polyethylene fiber for improved adhesion to epoxy resin. *Journal of Reinforced Plastics and Composites.* 27(7)**,** 671-682.

Atta, A.M., Shaker, N., Abdou, M. and Abdelfatah, M. (2006a). Synthesis and characterization of high thermally stable poly (Schiff) epoxy coatings. *Progress in organic coatings.* 56(2)**,** 91-99.

Atta, A.M., Shaker, N. and Maysour, N. (2006b). Influence of the molecular structure on the chemical resistivity and thermal stability of cured Schiff base epoxy resins. *Progress in organic coatings.* 56(2)**,** 100-110.

Augusto, O. and Andrade, B. (2003). Anchor deployment for deep water floating offshore equipments. *Ocean engineering.* 30(5)**,** 611-624.

Awaja, F., Gilbert, M., Kelly, G., Fox, B. and Pigram, P.J. (2009). Adhesion of polymers. *Progress in polymer science.* 34(9)**,** 948-968.

Baldan, A. (2004). Adhesively-bonded joints and repairs in metallic alloys, polymers and composite materials: adhesives, adhesion theories and surface pretreatment. *Journal of materials science.* 39(1)**,** 1-49.

Banfield, S. and Casey, N. (1998). Evaluation of fibre rope properties for offshore mooring. *Ocean Engineering.* 25(10)**,** 861-879.

Bartus, S. and Vaidya, U. (2005). Performance of long fiber reinforced thermoplastics subjected to transverse intermediate velocity blunt object impact. *Composite structures.* 67(3)**,** 263-277.

Basin, V. (1984). Advances in understanding the adhesion between solid substrates and organic coatings. *Progress in organic coatings.* 12(3)**,** 213-250.

Brockmann, W., Geiß, P.L., Klingen, J. and Schröder, B. (2009a). Adhesive bonding. Wiley-VCH Verlag GmbH & Co. KGaA Weinheim.

Brockmann, W., Geiß, P.L., Klingen, J. and Schröder, B. (2009b). Adhesive Bonding as a Joining Technique. *Adhesive Bonding: Materials, Applications and Technology*. 1-3.

Brückner, H., Frank, U., Fransen, H., Rasshofer, W., Schaper, H. and Schmidt, H.-U. (1991). PUR-RRIM ist recyclingfähig. *Kunststoffe*. 81(9)**,** 751-759.

Castell, P., Serra, A. and Galià, M. (2004). Liquid-crystalline thermosets from liquid-crystalline epoxy resins containing bisazomethinebiphenylene mesogens in the central core: Copolymerization with a nonmesomorphic epoxy resin. *Journal of Polymer Science Part A: Polymer Chemistry*. 42(14)**,** 3631-3643.

Chattopadhyay, D. and Raju, K. (2007). Structural engineering of polyurethane coatings for high performance applications. *Progress in Polymer Science*. 32(3)**,** 352-418.

Chemical, I. (2013). CILBOND 49SF® 49SF TECHNICAL DATA SHEET. USA: Chemical Innovations Limited.

Chen, M.-A., Li, H.-Z. and Zhang, X.-M. (2007). Improvement of shear strength of aluminium-polypropylene lap joints by grafting maleic anhydride onto polypropylene. *International journal of adhesion and adhesives*. 27(3)**,** 175-187.

Chetan Makadia, J.V., Viviana Wilson, (2014). High Temperature Thermoplastics Polyurethanes for Cable Jacketing Applications. Wire & Cable India.

Choi, E.-J., Seo, J.-C., Bae, H.-K. and Lee, J.K. (2004). Synthesis and curing of new aromatic azomethine epoxies with alkoxy side groups. *European polymer journal*. 40(2)**,** 259-265.

Easterling, K.E. and Thölén, A.R. (1972). Surface energy and adhesion at metal contacts. *Acta Metallurgica*. 20(8)**,** 1001-1008.

Funasaka, T., Ashihara, T., Maekawa, S., Ohno, S., Meguro, M., Nishino, T. and Nakamae, K. (1999). Adhesive ability and solvent solubility of propylene-butene copolymers modified with maleic anhydride. *International journal of adhesion and adhesives*. 19(5)**,** 367-371.

Giamberini, M., Amendola, E. and Carfagna, C. (1997). Lightly crosslinked liquid crystalline epoxy resins: The effect of rigid-rod length and applied stress on the state of order of the cured thermoset. *Macromolecular Chemistry and Physics.* 198(10)**,** 3185-3196.

Giles Jr, H.F., Mount Iii, E.M. and Wagner Jr, J.R. (2004). *Extrusion: the definitive processing guide and handbook.* William Andrew.

Giles, T.R. (2001). Pretreatment of various substrates prior to electrocoating. *Metal Finishing.* 99(9)**,** 10-20.

Gilliam, M. (2015). Polymer Surface Treatment and Coating Technologies. *Handbook of Manufacturing Engineering and Technology*. 99-124.

Golaz, B., Michaud, V. and Månson, J.-A. (2011). Adhesion of thermoplastic polyurethane elastomer to galvanized steel. *International journal of adhesion and adhesives.* 31(8)**,** 805-815.

Golaz, B., Michaud, V. and Månson, J.a.E. (2013). Photo-polymerized epoxy primer for adhesion improvement at thermoplastic/metallic wires interfaces. *Composites : Part A.* 48(17)**,** 171-180.

Hamzah, E., Hussain, M., Ibrahim, Z. and Abdolahi, A. (2013). Influence of Pseudomonas aeruginosa bacteria on corrosion resistance of 304 stainless steel. *Corrosion Engineering, Science and Technology.* 48(2)**,** 116-120.

Huang, X., Birman, V., Nanni, A. and Tunis, G. (2005). Properties and potential for application of steel reinforced polymer and steel reinforced grout composites. *Composites Part B: Engineering.* 36(1)**,** 73-82.

Hyun, C.M., Salleh, S., Ahmad, N., Ourdjini, A. and Hamzah, E. (2014). Influence of Carbon Content on the Mechanical Properties of Ultra-high Strength of Coated Steel Wire. *Jurnal Teknologi.* 69(1).

Ikuta, T., Komada, H. and Mutsuda, M. (2004). Molding thermoplastic resins, then bonding to silicone rubbers and vulcanization or crosslinking the rubbers, to form engineering thermoplastics having bonding strength, used in automobiles. Google Patents.

Ishida, H. and Akovali, G. (1993). The Interfacial Interactions in Polymer Composites. Kluwer Academic Publishers.

Julia Barges, J. and Ayuso Piqueras, J.L. (2001). POLYURETHANE CRYSTALLINE THERMOPLASTIC AND METHOD FOR THE PRODUCTION THEREOF. US Patent 20,010,051,694.

Kalpakjian, S. (1997). Superplastic Forming. *Manufacturing Processes for Engineering Materials, 3rd ed., Addison Wesley, Boston, MA.* 421-422.

Kamal, M. (2013). Adhesion properties of polymer coated steel wire for offshore applications. *Faculty of Mechanical engineering,*. Malaysia: Universiti Teknologi Malaysia.

Kendall, K. (1994). Adhesion: molecules and mechanics. *Science.* 263(5154)**,** 1720-1725.

Kinloch, A. (1980). The science of adhesion. *Journal of materials science.* 15(9)**,** 2141-2166.

Krylova, I. (2001). Painting by electrodeposition on the eve of the 21st century. *Progress in Organic Coatings.* 42(3)**,** 119-131.

Lamb, R. and Hashmi, M. (1991). Polymer coating of superfine wire: a new technique to ensure quality. *Journal of Materials Processing Technology.* 26(2)**,** 197-205.

Langer, E., Waśkiewicz, S., Kuczyńska, H. and Kamińska-Bach, G. (2014). Self-stratifying coatings based on Schiff base epoxy resins. *Journal of Coatings Technology and Research.* 11(6)**,** 865-872.

Lord, C. (2015). LORD TECHNICAL DATA Chemlok® 213 Adhesive. USA: Lord Cooperation Media World Wide.

Lu, J.Z., Wu, Q. and Negulescu, I.I. (2005a). Wood-fiber/high-density-polyethylene composites: Coupling agent performance. *Journal of Applied Polymer Science.* 96(1)**,** 93-102.

Lu, J.Z., Wu, Q. and Negulescu, I.I. (2005b). Wood-fiber/high-density-polyethylene composites: Coupling agent performance. *Journal of Applied Polymer Science.* 96(1)**,** 93-102.

Lubrizol. 2014. *Estane 58311 TPU* [Online]. Brecksville Road, Cleveland, Ohio: Lubrizol Advanced Materials. Available: www.lubrizol.com/engineeredpolymers [Accessed 11/7/2015 2015].

Martyn, M.T., Spares, R., Coates, P.D. and Zatloukal, M. (2009). Imaging and analysis of wave type interfacial instability in the coextrusion of low-density polyethylene melts. *Journal of Non-Newtonian Fluid Mechanics.* 156(3)**,** 150-164.

Mija, A., Cascaval, C., Stoica, G., Rosu, D. and Simionescu, B. (1996). Synthesis and characterization of some epoxy resins bearing azomethine groups. *European polymer journal.* 32(6)**,** 779-783.

Morris, H.R., Munroe, B., Ryntz, R.A. and Treado, P.J. (1998). Fluorescence and Raman chemical imaging of thermoplastic olefin (TPO) adhesion promotion. *Langmuir.* 14(9)**,** 2426-2434.

Morris, H.R., Turner, J.F., Munro, B., Ryntz, R.A. and Treado, P.J. (1999). Chemical imaging of thermoplastic olefin (TPO) surface architecture. *Langmuir.* 15(8)**,** 2961-2972.

Mutsuda, M. and Komada, H. (2005). Direct bonding between poly (oxy-2, 6-dimethyl-1, 4-phenylene) and rubber with radicals. *Journal of applied polymer science.* 95(1)**,** 53-59.

Ning, H., Pillay, S. and Vaidya, U.K. (2009). Design and development of thermoplastic composite roof door for mass transit bus. *Materials & Design.* 30(4)**,** 983-991.

Nistala, L. and Chris, B. (2011). Thermoplastic Polyurethane (TPU) in wire and Cable Applications. *Wire and Cable International.* (2)**,** 52-52. Blue Toad Publishers.

Ochoa-Putman, C. and Vaidya, U.K. (2011). Mechanisms of interfacial adhesion in metal–polymer composites–Effect of chemical treatment. *Composites Part A: Applied Science and Manufacturing.* 42(8)**,** 906-915.

Packham, D.E. (2003). Surface energy, surface topography and adhesion. *International Journal of Adhesion and Adhesives.* 23(6)**,** 437-448.

Packham, D.E. (2006). *Handbook of adhesion.* John Wiley & Sons.

Patel, C.J. and Mannari, V. (2014). Air-drying bio-based polyurethane dispersion from cardanol: Synthesis and characterization of coatings. *Progress in Organic Coatings.* 77(5)**,** 997-1006.

Pocius, A.V. (2012). *Adhesion and adhesives technology: an introduction.* Carl Hanser Verlag GmbH Co KG.

Qin, R.-Y. and Schreiber, H. (1999). Adhesion at partially restructured polymer surfaces. *Colloids and Surfaces A: Physicochemical and Engineering Aspects.* 156(1)**,** 85-93.

Rahme, R., Avril, F., Cassagnau, P., Sage, D., Verchere, D. and Doux, M. (2011). New polymer/steel solution for automotive applications. *International Journal of Adhesion and Adhesives.* 31(7)**,** 725-734.

Ramarathnam, G., Libertucci, M., Sadowski, M. and North, T. (1992). Joining of polymers to metal. *WELDING JOURNAL-NEW YORK-.* 71**,** 483-s.

Ribera, D., Serra, A. and Mantecón, A. (2003). Dimeric liquid-crystalline epoxyimine monomers: Influence of dipolar moments on mesomorphic behavior and the formation of liquid-crystalline thermosets. *Journal of Polymer Science Part A: Polymer Chemistry.* 41(10)**,** 1465-1477.

Ridge, I. (2009). Tension–torsion fatigue behaviour of wire ropes in offshore moorings. *Ocean Engineering.* 36(9)**,** 650-660.

Risser, S.M., Mcginniss, V., Nippa, D.W., Burrows, P.E., Padmaperuma, A.B., Kundu, S.N. and Mataki, H. (2015). Organic-inorganic complexes containing a luminescent rare earth-metal nanocluster and an antenna ligand, luminescent articles, and methods of making luminescent compositions. Google Patents.

Roussak, O. and Gesser, H. (2013). *Adhesives and Adhesion*. *Applied Chemistry.* (pp. 219-232). Springer.

Ryntz, R.A. (2005). Attaining durable painted plastic components. *JCT research.* 2(5)**,** 351-360.

Sharpe, L. and Akovali, G. (1993). The Interfacial Interactions in Polymeric Composites. *Akovali, ed.(NATO-ASI Ser. E: Applied Sciences, Kluwer, Dordrecht 1994) p.* 230.

Sharpe, L.H. (1974). Some thoughts about the mechanical response of composites. *The Journal of Adhesion.* 6(1-2)**,** 15-21.

Sharpe, L.H. (1998). Some fundamental issues in adhesion: A conceptual view. *The Journal of Adhesion.* 67(1-4)**,** 277-289.

Sonnenschein, M.F. (2014). *Polyurethanes: Science, Technology, Markets, and Trends.* John Wiley & Sons.

Sunwoo, K.B., Park, S.J., Lee, S.J., Ahn, K.H. and Lee, S.J. (2001). Numerical simulation of three-dimensional viscoelastic flow using the open boundary condition method in coextrusion process. *Journal of non-newtonian fluid mechanics.* 99(2)**,** 125-144.

Ter Meulen, B. (1983). Industrial Tpu Applications in Europe. *Journal of Industrial Textiles.* 12(3)**,** 148-159.

Thattaiparthasarathy, K.B., Pillay, S., Ning, H. and Vaidya, U. (2008). Process simulation, design and manufacturing of a long fiber thermoplastic composite for mass transit application. *Composites Part A: Applied Science and Manufacturing.* 39(9)**,** 1512-1521.

Verhoeven, V.W.A. (2006). The reactive extrusion of thermoplastic polyurethane.

Vickers, S. (2014). Adhesion promotion of polyurethane and epoxy coatings. *Reinforced Plastics*, (May/June 2014).

Wang, M. and Porter, D. (1994). Processing, characterisation, and evaluation of hydroxyapatite reinforced polyethylene. *British Ceramic Transactions.* 93(3)**,** 91.

Wolf, R.A. (2010). Plastic Surface Modification.

Xie, J., Luan, B.L., Wang, J., Liu, X.Y., Rorabeck, C. and Bourne, R. (2008). Novel hydroxyapatite coating on new porous titanium and titanium-HDPE composite for hip implant. *Surface and Coatings Technology.* 202(13)**,** 2960-2968.

Yacobi, B., Martin, S., Davis, K., Hudson, A. and Hubert, M. (2002). Adhesive bonding in microelectronics and photonics. *Journal of applied physics.* 91(10)**,** 6227-6262.

Yun, I.H., Kim, W.-S., Kim, K., Jung, J.-M., Lee, J.-J. and Jung, H.-T. (2011). Highly enhanced interfacial adhesion properties of steel-polymer composites by dot-shaped surface patterning. *Journal of Applied Physics.* 109(7)**,** 074302.

Zhang, Y. and Wang, L. (2011). *Microfluidics: fabrication, droplets, bubbles and nanofluids synthesis.* Springer.

Zhang, Z., Liu, Y., Huang, Y., Liu, L. and Bao, J. (2002). The effect of carbon-fiber surface properties on the electron-beam curing of epoxy-resin composites. *Composites Science and Technology.* 62(3)**,** 331-337.

Zia, K.M., Zuber, M., Bhatti, I.A., Barikani, M. and Sheikh, M.A. (2009). Evaluation of biocompatibility and mechanical behavior of chitin-based polyurethane elastomers. Part-II: Effect of diisocyanate structure. *International journal of biological macromolecules.* 44(1)**,** 23-28.