ANNALS OF THE ORADEA UNIVERSITY
Fascicle of Management and Technological Engineering
ISSUE #1, MAY 2013, http://www.imtuoradea.ro/auo.fmte/

SOME ASPECTS ABOUT FAILURES OF PLASTIC COMPONENT PARTS

Adrian-Petru POP[1], Gheorghe BEJINARU-MIHOC[2]
[1]University of Oradea, adippop@yahoo.com
[2]Transilvania University of Brasov, bejinaru_gheorghe@yahoo.com

***Abstract*—** The plastic materials are widely used in all cutting-edge of industries or domestic sectors with multiple applications. During of plastics' fabrication process can be occurred some failures that can have a negative influence about the final form of parts and the quality product of assemble. The main failures can be divided in types as crack, wear, deformation, degradation and esthetic alteration. This paper has the aim to present a few aspects of the evaluation of plastic failures and the analytical approach used to assess these failures to enhance the quality and lifetime prediction of plastic component parts.

***Keywords*—** Analytic Approach**,** Crack, Deformation, Failure, Plastic

I. INTRODUCTION

THE plastics represent organic materials that are solid in finished state, but were formed with heat and pressure by using a polymerization process. These materials can be classified in two main categories as thermoplastics and thermosets. Thermoplastics are those plastics that at room temperature are solid, but when heated they soften and can be reformed, vs. thermosts are those plastics that soften during original processing, but once finished they can't easily be reprocessed [1]-[7]. The polymers have a molecular structure that can include characteristics, as molecular weight, crystallinity and orientation, which due to a significant impact on the properties of molded items. Also, plastic resins usually contain additives that can be reinforcing fillers, plasticizers, colorants or anti-degradants and process aids [2], [3], [9].

The definition of failure is multiple and complex, which can be like as "the inability of a component, machine or process to function properly" to "a component that can no longer performs its intended function safety, reliably, and economically" [1]-[5].

A first failure's levels in function of the parts' functionality are:

- The part is operable, but is not fully functional;
- The part is functional, but has been compromised and is unsafe or unreliable for continued use;
- The part is completely inoperable.

The main failure types can be divided into followings:

- Fracture,
- Wear,
- Deformation or distortion,
- Degradation,
- Esthetic alteration.

Many of these failures can be avoided by understanding how the specific plastic being used behaves under a certain load at the expected environmental conditions.

The goal of this paper is to present the concept of plastic failures and the analytical approach to evaluate failures, with details in next.

II. METHODS USED FOR PLASIC FAILURES EVALUATION

Plastics can be failed with multiple modes or methods, such as catastrophic mechanisms that mean environmental stress cracking, molecular degradation and fatigue, brittle fracture, ductile overload, and creep rupture.

The plastic *Failure Analysis* is important because it solves the current problem by efficient using of time and resources, which imposed to respect the followings [5]-[8]:

- Advance information about of material, design, manufacturing methods and machine use, combined with testing methods.
- Identify ways to prevent the failures or enhance in current and future component parts.
- Determine the main symptoms of possible failures of plastic parts, which mean how the failures occurred and corrective measures to avoid these.

The steps used at failure analysis of plastic parts are:

- Collected background information of parts,
- Macro-inspection of parts,
- Samples,
- Micro-inspection of parts that involved testing of composition, molecular structure and physical properties;
- Determine failure mode and cause,
- Determine contributing factors,
- Prepare report,

- Design reviewer of simulate failures,
- Take corrective actions.

The main goal of the failure analysis represents the identification of mechanism and cause of the failure

At evaluation of plastic failures can be used a variety of methods or different techniques such as [1], [5], [6].

- *Fourier transfer infrared spectroscopy* (FTIR), which is used at analysis of material identification, contamination, degradation and chemical contact by measuring of molecular bound structure.
- *Differential scanning calorimetry* (DSC), used at analysis of material identification, level of crystallinity, aging/degradation and thermal history by measuring of multiple parameters as heat of fusion, melting point, glass transition temperature and heat capacity.
- *Thermogravimetric analysis* (TGA), used at analysis of composition, thermal stability and evolved gas analysis by measuring of weight loss over temperature or time.
- Thermomechanical analysis (TMA), used at analysis of coefficient of thermal expansion, material transitions, molded-in stress and chemical compatibility by measuring of dimensional changes over temperature.
- *Dynamic mechanical analysis* (DMA), used analysis of temperature-dependent behavior, aging/degradation and solid-liquid interactions by measuring of elastic modulus, viscous modulus and tan delta.
- *Gel permeation chromatography* (GPA), used at analysis of degradation, suitability of material for use by measuring of weight-average molecular weight and molecular weight distribution.
- *Melt flow rate* (MFR), used at analysis of degradation, compliance with material specification by measuring of melt viscosity.
- *Solution viscosity* is used at analysis of degradation by measuring of intrinsic viscosity.
- *Mechanical testing* is used at analysis of compliance with material specification and mechanical properties by measuring of strength and elongation properties, and modulus.
- *Scanning electron microscopy* (SEM) is used at analysis of facture mod by determination of surface and particle morphology.
- *Energy dispersive x-ray spectroscopy* (EDS) is used at analysis of material composition, fillers and additives by determination of elemental concentrations.
- *Nuclear magnetic resonance* (NMR) is used at analysis material identification by determination of molecular bond structure.
- *Mass spectroscopy* (MS) is used at Material identification, additives by measuring of Molecular structure.
- *X-ray photoelectron spectroscopy* (XPS) is used at analysis of chemical composition of surfaces by measuring of elemental concentrations.
- *Auger electron spectroscopy* (AES) is used at analysis of chemical composition of surfaces by measuring of elemental concentrations.

An important element in the failure analysis of plastic parts represents the evaluation of plastic performance factors, which means the analysis of material factors and design factors and service conditions..

The *analysis of material factors* involves the evaluation of plastic material composition, which can be:

- Base polymer: structure of functional group, homopolymer and copolymer.
- Intentional additives: anti-degradants, colorants and fillers.
- Bulk contamination.

At level of molecular structure is required to assessing:

- Molecular weight distribution
- Average molecular weight
- Crosslinking at thermoplastic or thermoset
- Crystallinity: amorphous or semi-crystalline.
- Branching.

The *analysis of design factors* involves the evaluation of plastic material composition that can be:

- Design factors that affect performance of plastic parts, such as:
    - Material selection
    - Wall thickness
    - Existence or no of ribs, bosses, threads, holes, snap fits, inserts
    - Plastic flow of material
    - Gating
    - Venting.
- Part design that means:
    - Selection/specification
    - Poor of material or tread design
    - Non-uniform or insufficient wall thickness
    - Inadequate corner radius
    - -Improper service contamination:
        - Chemical contact
        - Creep
        - Fatigue
        - Impact
    - Design for metals.
- Tool design that means:
    -Raped and uneven cooling
    - Poor fusion
    - Warpage
    -Trapped air.

The *service conditions* of plastic failure analysis include:

- Impact speed
- Impact fatigue
- Temperature
- Striker geometry

A. Fractography

Fractography is the widely method used at evaluation of plastic failures analysis. This examination provides real information about of cracked or surface damaged of plastic part analyzed [1], [5], [6]:

- Fracture created with tensile testing
- Significant macro-ductility apparent on samples
- Cracking initiated as discontinuity
- Cracking origin within mid-wall

Fractographic examination used at plastic failures analysis involves determination of:

- Location of crack initiation
- Mechanism of crack initiation
- Manufacturing defects
- Damages.

Cracking can be explained as a mechanism of stress relief in which the material is attempting to reach a lower energy state. Plastics fail through a disentanglement mechanism in which polymer chains slide past each other. In general, cracking can be divided into ductile or brittle after significant deformation and yielding. Ductile fracture occurred after great deformation and yielding, being a bulk molecular response followed by disentanglement. Brittle fracture represents a response where disentanglement is favored over yielding. Microscopically, ductile fracture surfaces exhibit the formation of stretched fibrils, vs. brittle fracture is characterized by minimal deformation or elongation.

Scanning electronic microscopy (SEM) is most used method to identify and study of fracture surfaces of plastics, with examples [1] presented in Fig. 1 and Fig. 2.

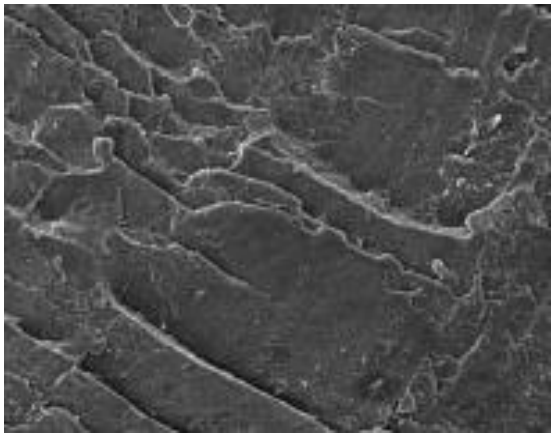

Fig. 1. SEM picture with brittle fracture surface of polymer [1]

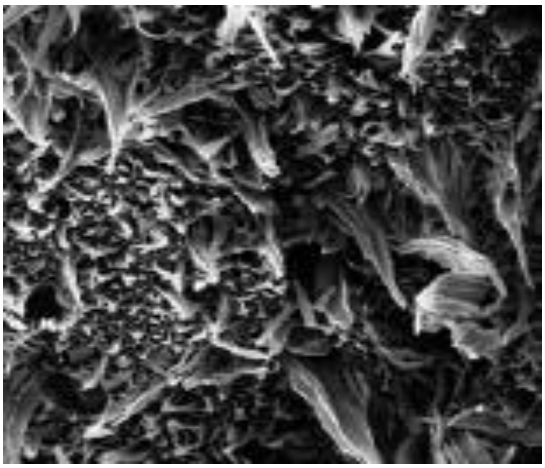

Fig. 2. SEM picture with ductile fracture surface of polymer [1]

B. Fourier Transform Infrared Spectroscopy (FTIR)

Fourier transform infrared spectroscopy represents a nondestructive micro-analytical spectroscopic technique that involves the study of molecular vibrations, which offers information about the composition and state of the material evaluated [5].

FTIR is used infrared energy to produce vibrations into the molecular bonds of material tested. The transition from one vibrational state to another is assured by absorption or emission of electromagnetic radiation. FTIR produces a unique spectrum that is comparable with the fingerprint of material, used a qualitatively identification of polymeric material [5].

The application of FTIR at plastic failures analysis involves:

- Material identification of plastic failure part
- Identification of material contamination
- Qualitative assessment of polymer, copolymer and blends
- Determination of molecular degradation
- Identification of chemical agent in contact with failed part.

C. Differential Scanning Calorimetry (DSC)

Differential scanning calorimetry is a thermal analysis technique where it can be measured the temperature and the heat flow associated with material transitions as a function of time and temperature [1], [5].

The difference in the amount of heat required to increase the temperature a sample and reference is measured to provide information regarding composition and structure, with an example presented in Fig. 3 [1].

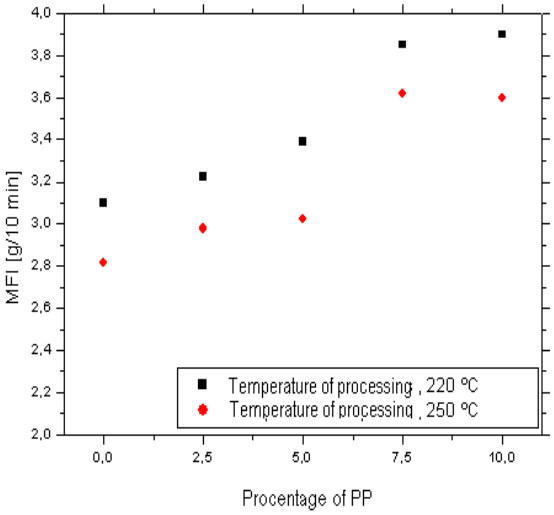

Fig. 3. Diagram of thermal analysis of PP at temperature of processing of 220°C, and respectively of 250°C [1]

The application of DSC in failure analysis of plastic parts involves the followings:

- Material identification:
  - Polymer identification
  - Copolymer type differentiation

- Copolymer vs. Homoplymer
- Material condition:
  - Degradation
  - Contamination
  - Oxidative stability
- Materials properties-heat history:
  -Crystallinity
  -Thermal history
  -Heat of reaction.

Samples with thermal behavior of PP (Fig. 4) and thermal degradation of PP (Fig. 5) are presented below.

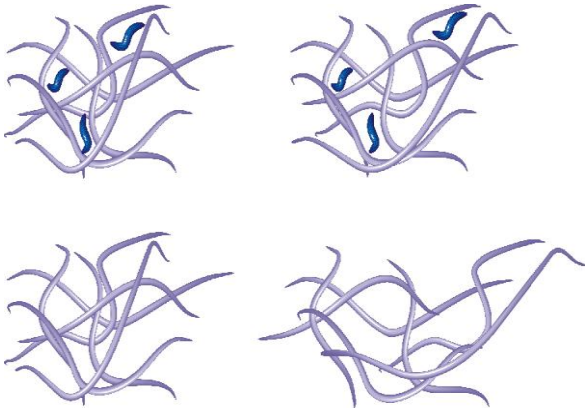

Fig. 4. Samples with thermal behavior of PP [1]

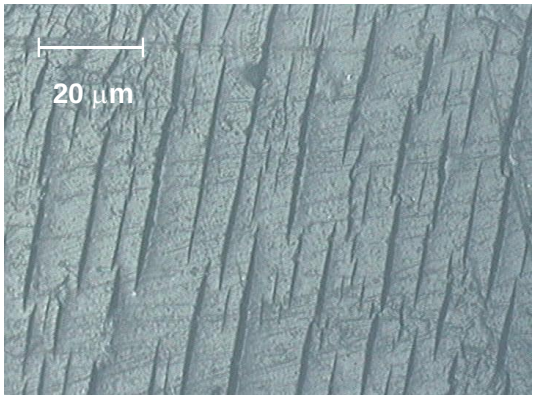

Fig. 5. SEM picture with presentation of the degradation grad of PP [1]

D. Thermomechanical Analysis (TMA)

Thermomechanical analysis is a thermal analysis technique where is measured a linear of volumetric dimensional changes as a function of temperature, time or forces. This method is used to assess the structure of a polymer material by evaluation of dimensional changes as expansion or contraction.

The parameter used for evaluation is the coefficient of thermal expansion (CTE) which represents the change in the length of a plastic material as a response to a change in temperature [1], [5], [8].

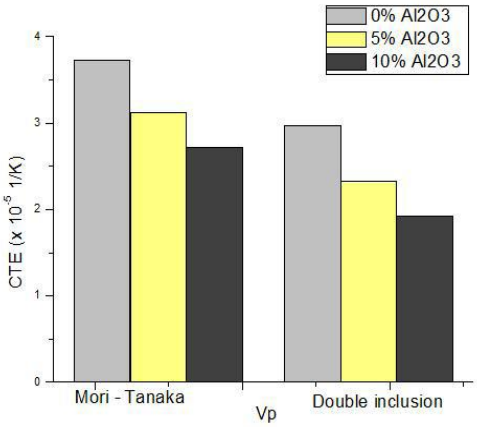

Fig. 6. Theoretically predicted effective CTE for all polymeric composite samples [8]

III. CONCLUSION

The paper has presented some aspects regarding of failures analysis approach of plastic components which can occurred during of plastic fabrication or manufacturing process and can effected the quality and lifetime prediction of final parts.

The methods or techniques used for this evaluation of plastic failures are multiple and differently, which required specific conditions and measures in concordance with the type of plastics, design and manufacturing process of parts, and environmental conditions or services that involved the occurrence of defects.

REFERENCES

[1] R. Balart, L.M. Lopez., L. Sanchez, A. Nadal, *Introduction in science engineering of polymer (English Translation)*, *Introduction a la ciencia e ingineria de polimeros*, Algrafic Editor, Alcoy, Spain, 2001, pp.103-190.

[2] G.F. Schrader, A.K. Elshennawy, *Manufacturing process and materials*", Fourth Edition, SME Editor, Dearborn, MI, USA. 2000, pp.111-139.

[3] P.D. Rufe, *Fundamentals of manufacturing,* Second Edition, Society of Manufacturing Engineer Editor, Dearborn, MI, USA, 2002, pp.227-235.

[4] P.D. Rufe, *Fundamentals of manufacturing Supplement*, Society of Manufacturing Engineer Editor, Dearborn, MI, USA, 2005, pp. 99-136.

[5] J.A. Jensen, *Tools and techniques in failure*, Chapter *Characterization of plastics in failure analysis*, ASM-The Madison Group, 2011, pp.430-459.

[6] J.A. Jensen, "Ductile to brittle transition of plastic materials", *Advanced Material & Processing J.*, Feb.2006, pp.39-44.

[7] P.A. Pop, *"MEMS- Introductive elements",* University of Oradea Ed., ISBN 978-606-10-0249-8, Oradea, 2010, pp.25-82

[8] P.A. Pop, D. Luca Motoc, , G. Bejinaru Mihoc, "Sizing extreme environmental condition influences on the multiphase polymeric composites' CTE" *Proceedings of ASME Conference-MSEC2011*, June 13-17, 2011, Corvallis, Oregon, USA, pp.1-7, 2011.

[9] P.A. Pop**,** P. Ungur**, M.** Veres, C. Gordan, "Rheological aspects to horizontal rotational forming of thermoplastic materials"**,** *Proceedings of ASME Conference MSEC2008/ICMP2008*, October 7-10, 2008, Evanston, Illinois, USA, pp.1-7, ISBN 0-7918-3836-6, ASME International, 2008.