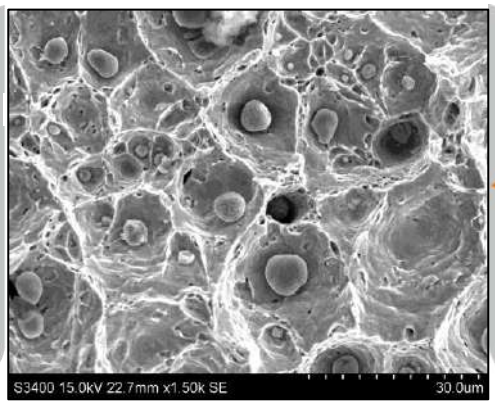
Journal of Materials, Manufacturing & Failure Analysis for Structural Integrity

SFA Mumbai Chapter



PHCET
PILLAI HOC COLLEGE OF ENGINEERING & TECHNOLOGY

Hosted By

15th November 2022 No.2 Vol.2

http:// www.sfa.mes.ac.in

PILLAI HOC COLLEGE OF ENGINEERING & TECHNOLOGY RASAYANI

News at a Glance

- From the editor's desk
- Journal Launched under the leadership of Dr. K. M. Vasudevan Pillai, Founder Chairman & CEO of MES & Dr.Daphne Pillai, Secretary MES

Dr. K. M. Vasudevan Pillai
Chairman & C. E. O
Mahatma Education Society

Dr. Daphne Pillai
Secretary
Mahatma Education Society

- Failure Analysis of Engineering Components Using Fishbone Diagram
- Events Organized /Forthcoming:
- Contributory Papers accepted for presentation to MET+HTS 2022 International Conference & Exhibition on Materials, Engineering, Technology and Advances in Heat Treatment

Dates: Wed. 2nd - Fri. 4th November 2022, Venue: Bombay Exhibition Center, Mumbai, India

- Mechanical Properties and Fracture characteristics of 3D Printed PLA
- Processing, Mechanical Properties and Fracture Characteristics of EPDM & HDPE Composites

Startup Project Incubated at IIC@PHCET entry titled "Solar Powered Vehicle" accepted to the innovation pavilion that is a part of MET+HTS 2022 to be held from 2nd to 4th november at the the Bombay Exhibition Center, Goregaon East Mumbai.

Editor: Prof. R.C. Prasad(rcprasad@mes.ac.in)

From Editor's Desk

WELCOME TO THE SECOND ISSUE OF THE JOURNAL

The journal is an integral part of the Society for failure analysis Mumbai chapter and the Institute Innovation Council at the Pillai HOC College of Engineering and Technology .

The first issue of the Journal was launched on September 15,2021, to cover topics related to materials, manufacturing and failure analysis . The manufacturing sector alone in India is expected to be 1 trillion USD by 2025. The industry today is powered by robotics,automation,additive manufacturing (3D Printing). Anything that is routine and repetitive is at the verge of getting automated. This has disrupted the relationship between industries and the technical institutes of higher education. To empower the manufacturing sector , continuous skilling of people and R&D is required. The way forward is to enhance industry experience for students and faculty, bridge the knowledge gap between existing course curriculum and the actual requirements of the industries and connect research with industrial problems , transform students towards self regulated learning (SRL) to enhance their performance for employment. The way forward is to provide outcome based training and learning that is futuristic. The focus today has to shift from learn to do to learn by doing. The onus of developing right skill is left to job seekers. This has provided us an opportunity to transform educational ecosystem to meet the requirements of the industries. At the Pillai HOC College of Engineering & Technology , have taken several initiatives in the last one year through Institute-Industry-Professional Society interaction programs to improve the quality of technical education to meet the local and global challenges through Teaching-Research Synergy and Academia – Industry Interaction.

I appeal and invite authors from academic institutes and reserch establishments to contribute manuscripts of their papers. Submission implies that the work has not been published earlier, except in the form of abstracts , lectures, academic theses. It may be a research paper, review paper or a short communication. One of the authors may be designated as the corresponding author with his affiliation and email. Please use spell check and grammar check to avoid errors. The structure of article should consist of Abstract with key words, Introduction, Materials & Methods, Experimental, Results & Discussion followed by references. The style of reference should be as in any standard journal like the Journal of Engineering Failure Analysis published by Elsevier.

LET US LOOK FAILURE ANALYSIS THROUGH THE LENS OF RESEARCH,INNOVATION & ENTERPRENURESHIP

Failure Analysis of Engineering Components Using Fishbone Diagram

Dr. R.C.PRASAD
Ex. Professor IIT Bombay
Professor
Department of Mechanical Engineering, PHCET Rasayani

Introduction :

The Fishbone diagram looks like a fish skeleton. The head of the diagram represents the desired result (output) that is preceded by bones (potential causes and effect). The fishbone diagram was inspired by lesson learnt from World War II and the method developed was called Value Engineering. The Value Engineering and Functional Analysis were considered too complex by Engineers. However it was thought that the method can be applied to improve quality in any discipline. The initiation of any investigation is to decompose its components element into taxonomy of categories. Logical division of taxonomy breaks down categories and represents sub groups graphically in the form of a Tree diagram. Consulting firm McKinsey calls the type of break down a mutually exclusive and collective exhaustive analysis.

Ishikawa introduced the Fishbone analysis in 1960s[1]. He used four 'M' s to describe core categories: Measurement that was later extended into six 'M's adding manpower and mother nature. A preferred version adds a seventh 'M' money Figure 1.

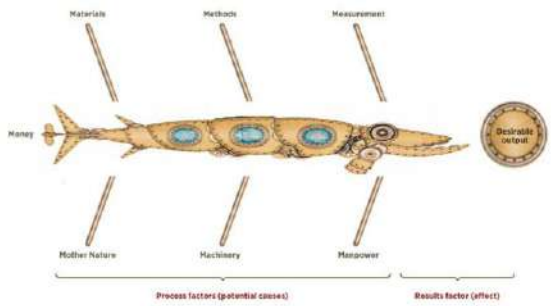


Figure 1 : Fishbone Diagram with Seven 'M's[1]

Quality Progress, Date:August 2019 Issue:Volume 52 Issue 8 :pp. 14-23

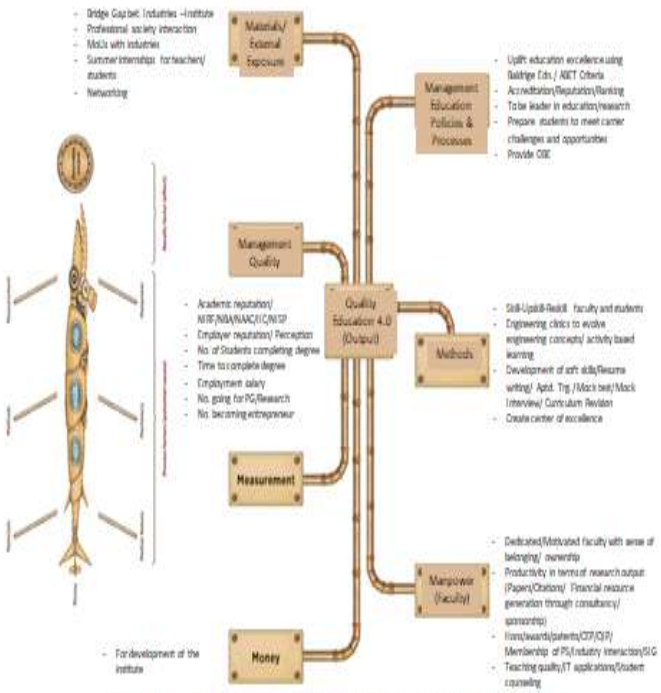


Figure 2 : Graphical Fishbone Analysis is Supported by Mind Map in the Digital Era[1]

Fig. 2 Illustrates the logical structure of a fishbone diagram expressed as a mind map. It consists of the main idea (process output of head of fish) at the centre that expands outward into branches that are represented as 7 'M's in fishbone analysis. The iconic Ishikawa diagram can be enhanced significantly using the mind mapping approach in the digital era for any discipline. An example is illustrated for quality education 4.0 in higher educational institutes.

Fishbone analysis of Crankshaft:

A typical Crankshaft shown consists of a fully single piece consisting of main shaft, crank web, crank pin journal, counter weights and crank gears. The journal rotates inside bearing and is secured to the ends of connecting rods which run the pistons that is multicylinder (more than 1 piston attached to the main shaft).

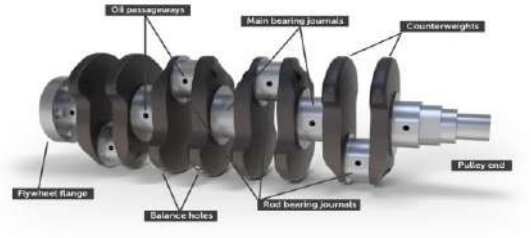


Figure 3 : A typical main shaft consists of a fully single piece consisting of main shaft, crank web, crank pin journal, counter weights and crank gears.

The main shaft in textile machinery is a critical component that transmits power from motor to machinery at a required speed and controls complete operation. The failure of the main shaft results in the breakdown of the entire process.

The main shaft is classified on the basis of material used, process of manufacture (forged / cast), on the basis of use (still / compressor) and on the basis of number of cylinders used (single / multi cylinder).

Details of a 400 kg/cm^2 URACA Pump

The pump unit comprises a fluid pump that operates on displacement principle where an electric motor serves as a drive. The unit has safety valves (press adjustment). The transport medium is outgassed demineralised water without chemical additives. The operating temperature is 10.16^{0}C and steam pressure at operating temp is 0.12 bar. The pH of transport medium is 6.5 – 7.5; solid content max 20 ppm with size of solid particles 50 μm max.

There are 5 plungers with diameter of 60 mm and plunger stroke 100 mm with integrated gear unit . Intake pressure at supply connection of running pump minimum 3 and maximum 6 bars.

The Operating Data

Parameter	OP1 Bar	OP2 Bar	OP3 Bar
Operating press between pump & resonator	400	400	-
Safety valve responses	400	440	440
Differential press for drive design	397	397	-

Parameter	Minimum	OP1	OP2	Maximum
Transport flow lpm	175	709	493	709
Pump Speed rpm	130	525	363	525
Motor Speed rpm	465	1880	1318	1880

The pump may not operate without lubrication and minimum speed. The pump was properly operated and maintained. The pressure gauge / thermometer displays were in normal range. The pump was stopped when vibration and sound was noticed.

The pump unit operates under internal pressure and therefore mechanical accidental damages can arise. However no symptom was observed in the present failure.

The material of construction of the main shaft is forged Cr – Mo steel in quenched and tempered condition. The steel has high toughness and therefore used for main shaft / connecting rod / gears / wheels and pinions. In the present case the crankshaft was forged.

A typical schematic of the fabrication of main shaft is given below Fig. 4.

Bloom
↓
Forged to shape
↓
Trimming
↓
Q & T / Normalising (800-850^0 C area)
↓
Machining
↓
Induction hardening / Nitriding / Shot peening
↓
Stress relieved 180^0 C to 2 hrs.

Figure 4 : A typical schematic of the fabrication of main shaft by forging process

In order to get sufficient / desired compressive stress in the fillet region, the main shaft transition region is hardened by nitriding, induction hardening, fillet rolling (hard rolling in fillet region) and shot peening.

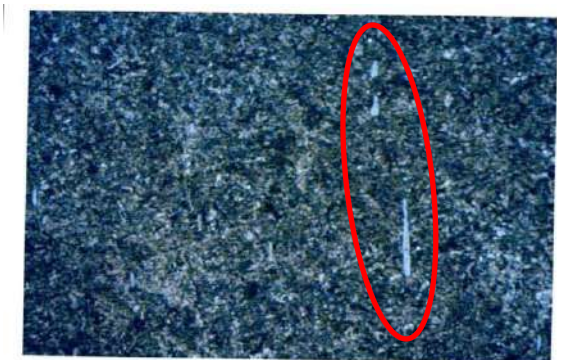
Failure Investigation

The chemical composition, mechanical properties (tensile, impact & hardness) and the microstructure was investigated as per ASTM standards. The results are listed in the subsequent sections. The chemical composition of material used for construction of crankshaft is within specified range Table 1.

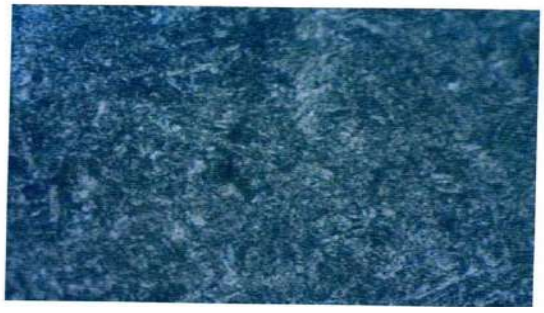
Table 1: The specified and analysed chemical composition of material 42 Cr Mo4 Steel.

Identification	Element %								Remark
Parameter	C	Mn	P	S	SI	Cr	Ni	Mo	Meet specified requirement of DIN 1.7225 / 42CrMo4 Steel
Specified	.38-.45	.75 – 1.0	.035 max	.04 max	.15 - .35	.8 – 1.1	-	.15 - .25	
Analysed	.43	.75	.01	.021	.28	1.1	.15	0.18	

The microstructure both in longitudinal and transverse directions at different magnifications consist of tempered martensite with retained austenite Fig 5 (a – d). The structure appears to have banded network along with aligned sulphide inclusions (incircled) that are known to facilitate crack initiation.

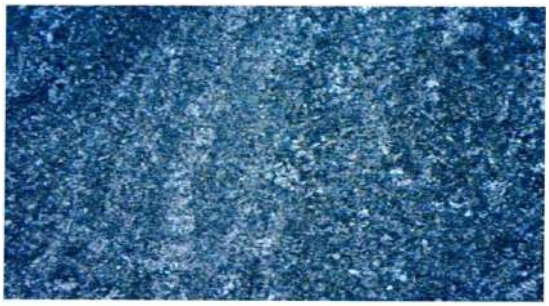


(a)



(b)

Fig.5 : Microstructure in Longitudinal direction at different magnification a) x 200 & b) x 500



(c)

(d)

Fig.5 : Microstructure in Transverse direction at different magnification a) x 200 & b) x 500

Table 2: The specified and analysed Mechanical Properties of the material in Q & T condition for dia > 160 - 250 mm. The analysed ductility and impact toughness values are from two tests each conducted at NABL Accredited Lab.

Identification	Tensile			
Parameter	Yield Stress (MPa)	UTS MPa	% Elongation	% RA
Specified	500 – Min	750 – 900 Min	14% Min	55 Min
Analysed	684 / 668	888 / 879	19 / 19.29	48 / 42

Identification	Impact Toughness	
Parameter	CVN (J)	
Specified	35 J Min – 53 J Average	
Analysed	Longitudinal 50 / 46 J	Transverse 58 / 52 J

Identification	Hardness	
Parameter	HVN	Equivalent RC
Analysed	270 / 272 / 274	26 / 26 / 20

The tensile strength and impact value given in Table 2 are on the higher side towards the maximum limit. It may be noted that as strength increases the ductility and toughness decreases.

About the Failure

The pump failed after 6 years service (20,000 hrs) .

The photographs of the failed main shaft of pump are shown in Fig 6 (a & b) and Fig. 7 (a & b). Most of the fractures in main shaft are reported to take place due to bending loads on fillets and or torsion load on main journal. Bending fatigue cracks grow from fillet. Torsional fatigue crack start in journal and spiral around at 45^0 angles. The material with high strength 800 MPa along with low impact stress and ductility combined with aligned sulphide inclusions and other defects can facilitate crack initiation. The crack propagation is faster when bending stress is relatively high. The bending load may be high due to misalignment and vibration during operation.

Fig. 6 (a) : Macrofractograph of the failed crankshaft reveals that the fracture took place in the web region between 4^{th}–5^{th} journal and 5 th crankpin

Fig. 6 (b) : Macrograph of the fracture surface of the failed web reveals that the crack initiates at fillet region of crankpin and counter wt. and is inclined at 45^0 to the shaft axis

The bending failure due to fatigue has flat smooth fractured faces with ductile final fractures and beach marks (arrest lines) radiating away from the initiation site Fig. 7 (a & b).

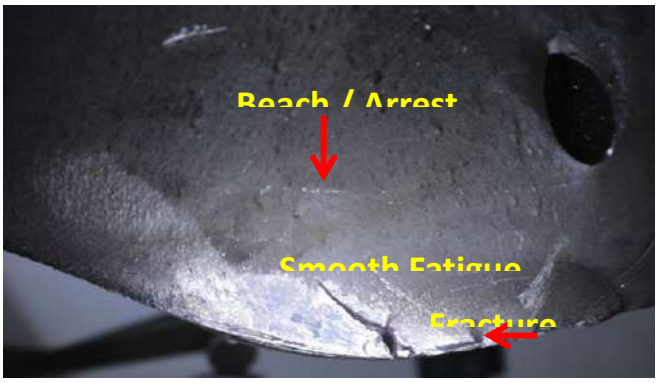


Fig. 7 (a): Fracture takes place at the fillet that bears maximum operational load.

Fig. 7 (b) : The crack appears to propagate due to cyclic bending Fig.7 (a) and steady torsion fig 6 (b).

Torsional failure shows ratchet marks pointing towards the initiation site. These arrest line indicates multiple cracks due to torsional failure.

Results & Discussion:

The reasons for main shaft failure was analysed through chemical composition, mechanical properties, macro fractography and micro structural evolution. The analysis of result reveals that the failure is brittle in nature caused by a combination of bending and torsional stresses. It consists of initiation and propagation stages. The small numbers of radiating marks Fig. 6 (b) may also be due to post deformation in a short time. The crack starts at fillet region that is a stress concentration site and can decrease the

failure life of the crankshaft drastically. The bending failure has flat smooth fractured faces with ductile final fractures and beach marks (arrest lines) radiating away from the initiation site. Torsional failure starts in journal and spiral around at 45^0 angles. The material with high strength 800 MPa stress, low toughness in combination with aligned sulphide inclusions and other defects can facilitate initiation of cracks. The crack propagation is faster when bending stress is relatively high. Torsional failure shows ratchet marks pointing towards the initiation site. These arrest line indicates multiple cracks due to torsional fatigue failure.

Failure Modes & Effects Analysis (FMEA)

Majority of failures of main shaft is due to cyclic loading. The failure crack initiation takes place at mechanical and or metallurgical notches such as:

- Regions of discontinuity
- Regions of irregularities
- Internal cracks due to material defects
- Design and production defects

The premature failure of the main shaft may be due to increasing severity of failure stress and or defects Fig.8.

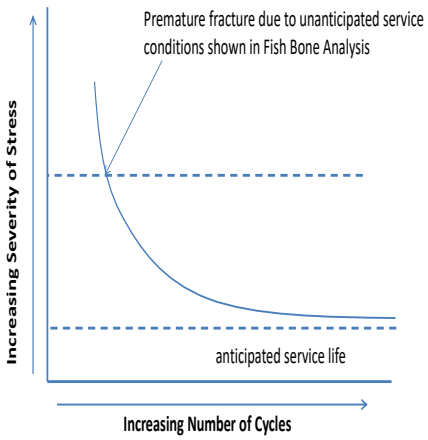


Fig. 8 : Failure Life Design showing effects of increasing the severity of the service condition

The cause effect analysis in the form of Fishbone diagram is given in Fig 8.

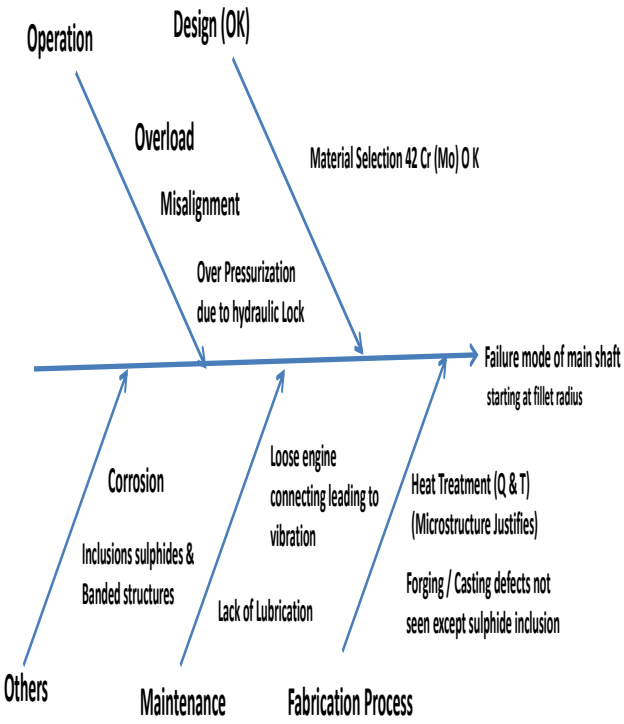
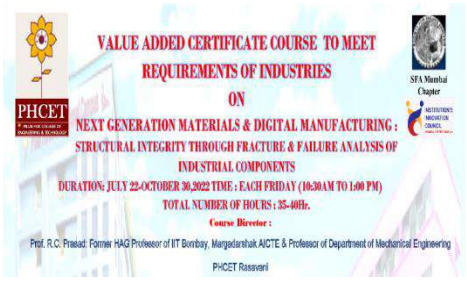


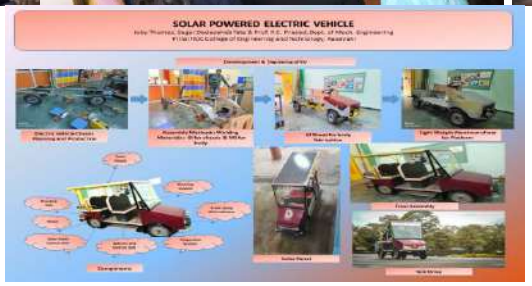
Fig.9: Cause Effect Analysis in the form of a Fishbone Diagram

Conclusion

The reason for failure in the present case appears due to fatigue starting from the stress concentration site shown in fig (4 a & b).The cause effect analysis in the form of FMEA con identifies and lists all modes of failures and the factors contributing towards that. In order to prevent future failures all the factors listed in the Fishbone analysis needs to be evaluated periodically. The alignment of the main shaft and condition monitoring for vibration is recommended. It is advisable to optimise fillet radii and inducing compressive stresses at the fillet.

Events Organised/ Forthcoming





Participation in the International Conference and Exhibition on Materials Engineering & Technology and Advances in Heat Treatment at Bombay Exhibition Center, Mumbai during November 02-04 , 2022

A Report

A paper titled "3D Printing Of Thermoplastics: Mechanical Properties and Fracture characteristics of 3D Printed Biodegradable PLA" that was jointly authored under the guidance of my project guide Prof. R.C. Prasad was presented on Nov. 4, 2022. Some of the glimpses of participation are given below:

Mr. Sagar D Tate on the dais presenting the paper and giving outline of his presentation

The Chairman of the session congratulated for the nice maiden presentation by an UG student


CERTIFICATE OF PARTICIPATION

ASM INTERNATIONAL INDIA CHAPTER

MET+HTS 2022 www.met-hts.com

409, Srishti Square, LBS Marg, Bhandup West, Mumbai, India.

This is to certify that **Mr. Sagar D Tate** from **Pillai HOCOE, Rasayani**, has presented a paper on **Processing, Properties and Fracture characteristics of 3D Printed PLA** in the International Conference and Exhibition on Materials Engineering & Technology and Advances in Heat Treatment organized by ASM International, India Chapter during November 2nd to 4th, 2022 at Bombay Exhibition Centre, Mumbai.

Pradeep Goyal, Chairman, Organising Committee MET + HTS 2022

Sudhakar Bonde, Secretary, Organising Committee MET + HTS 2022

Prof. V.S Raja, Chairman, Technical Committee MET + HTS 2022 conference

The Chairman of the session presenting the Certificated to Mr. Sagar D Tate

Entry titled " Solar Powered Electric Vehicle " under Startup Category that was incubated under the umbrella " Institution Innovation Council @ PHCET was accepted for poster presentation to the Innovation Pavilion , a part of the Exhibition MET + HTS - 2022 held during November 2-4,2022 at the Bombay Exhibition Ground Goregaon , Mumbai

Mr. Joby Thomas and Prof. R.C. Prasad in the Pavilion Exhibition Stall allotted to PHCET for the display of the posters

Mr. Joby Thomas explaining the Solar Powered Electric Vehicle to the visitors from different Engineering Colleges

Dr. U. Kamachi Mudali, Vice Chancellor of VIT Bhopal University and Prof. V.S. Raja , IIT Bombay, Chairman of Technical Committee visited the Pavilion Exhibition Stall

Mr. Rajesh Shah, Joint Secretary of the Organizing Committee along with delegates from different parts of the Country visited the Pavilion Exhibition Stall

Mr. Shankar G Subburathinam , Engineering Manager, Advanced Material Technology, Innovation Technology and Development Division of Caterpillar India Pvt. Ltd. Thiruvallur visited the Pavilion Exhibition Stall

Mr. Samar Gupta, CEO of OHT Fasteners Rabale, Mumbai visited the Pavilion Exhibition Stall

Posters exhibited in the Innovation Pavilion Stall allotted to The Pillai HOC College of Engineering & Technology at the MET+HTS 2022 International Conference & Exhibition during November 2- 4, 2022, at Bombay Exhibition Center, Mumbai

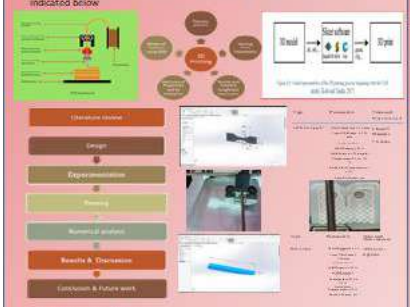
Poster accepted for presentation to MET+HTS 2022 International Conference & Exhibition on Materials, Engineering, Technology and Advances in Heat Treatment
Dates: Wed. 2nd - Fri. 4th November 2022, Venue: Bombay Exhibition Center, Mumbai, India

Mechanical Properties and Fracture characteristics of 3D Printed PLA

Sagar Dadasaheb Tate, Tejesh S. Vaskar & Prof. R.C. Prasad, Dept. of Mech. Engineering, Pillai HOC College of Engineering and Technology, Rasayani

Introduction

3D printing is a high tech disruptive manufacturing process of making products layer by layer. However, strength of such 3D printed parts using specific materials is still an area of current research. Traditional manufactured parts are isotropic and homogeneous due to applied pressure. But 3D printed parts have layered structure and contain imperfections like voids and may not be highly packed.
The fabricated components / medical implants are evaluated on the basis of mechanical and environmental durability. There is no method currently available to predict mechanical properties without physical testing the finished product. In this paper the Mechanical properties & Fracture toughness results of PLA fabricated by FDM process with different infill density are presented and the variation in mechanical properties evaluated. The schematic plan of work is indicated below

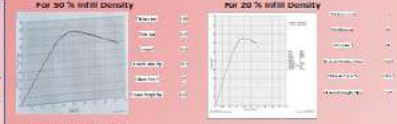


Experimental and Results
Material used
Poly(lactic acid) or polylactide (PLA)
Chemical Formula : $(C_3H_4O_2)_n$

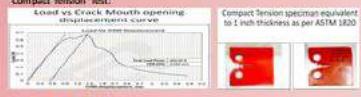
Slicing Software used
Ultimaker Cura
Ultimaker Cura works by slicing the user's model file into layers and generating a printer specific g code. Once finished, the g code can be sent to the printer for the manufacture of the physical object.

Results
Tensile Test:

Flexural Test



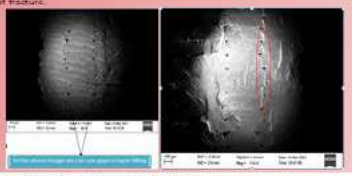
Compact Tension Test:



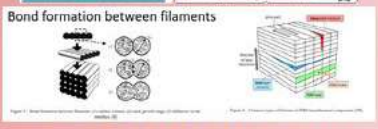
Varying Parameters
Build Orientation /Temperature /Layer height/ Infill density/Speed /Infill Pattern

The Mechanical test results indicate that increased infill density increases both the tensile and flexural properties. This may be attributed to reduction of voids and imperfections. The load crack tip opening displacement curve obtained on CTS sample indicates that the 3D printed PLA initially has linear slope, followed by stable crack growth. This is indicative of the fact that PLA has enough crack resistance capability and cannot be termed as brittle material.

Fractography
Specimens with 20 % infill density were scanned under Scanning Electron Microscope to understand orientation of layer and to find out if there were any voids or gaps in infill. The Tensile and Flexural tested specimens were examined under ESEM to find the modes and mechanisms of the fracture.
The fractured surfaces were examined under ESEM to find modes & mechanisms of fracture.



Bond formation between filaments



In this image we can see the fractograph after testing that the materials has failed due to formation of void/ Gaps in layer. A crack line is clearly visible passing from void/gaps in layer in the figure as well as the schematic shown. By increasing infill density and using small nozzle and small layer thickness, gap and voids could be avoided.

Scope for Future Work
A large number of people in different parts of country living in rural area are dependent on ground water for drinking. They are affected by arsenic contamination of water that leads to cancer of lungs/ bladder /liver/skin/kidneys and several neurological disorders.
The knowledge gained so far can be utilized to develop a reusable adsorptive filtration device for arsenic removal at low cost without the use of electricity. A computer aided design of four differently sized filters and channel widths of 0.8, 1.0, 1.8 and 4.0 mm are shown below.

Poster accepted for presentation to MET+HTS 2022 International Conference & Exhibition on Materials, Engineering, Technology and Advances in Heat Treatment
Dates: Wed. 2nd - Fri. 4th November 2022, Venue: Bombay Exhibition Center, Mumbai, India

Processing, Mechanical Properties and Fracture Characteristics of EPDM & HDPE Composites

Mr.Kunal Bharat Patil & Dr. R.C. Prasad, Dept. of Mech. Engineering, Pillai HOC College of Engineering and Technology, Rasayani

Abstract
The paper presents the results of the studies on the mechanical properties and fracture characteristics of a biodegradable viscoelastic ultra high molecular weight Ethylene Propylene Diene monomer (EPDM), a synthetic rubber that was blended with a recyclable High density polyethylene (HDPE) thermoplastic in bra bender and two high mill and compression molded.
Toughness of the composite blends containing varying content of EPDM was determined by impact test. The impact strength was found to increase with increase in EPDM due to its ductile nature. The fracture located near notch tip consists of crack initiation and propagation. High speed and triaxial stress at the notch tip show defor mation bands that look like crazes in the form of river lines. At lower fracture speed the fracture morphology changes to dimples aligned in the crack propagation direction.
On the contrary the tensile strength was found to decrease with the increase in EPDM
The tensile Fractographs observed in ESEM are typical of two dissimilar polymers containing fillers that influence movement of viscous elastic polymer in highly crystalline linear molecular HDPE

Introduction:
Natural/Synthetic (EPDM) are biodegradable and recyclable elastic material having high elongation and good damping capacity. Pure rubber becomes brittle with temperature variation, however, EPDM withstand temperature variations for decade. All rubber materials defects/flaws generated during fabrication or service. To avoid failures in rubber engineers add thermoplastic HDPE that is a popular flexible weather proof thermoplastic. Composites made of biodegradable EPDM and recyclable HDPE is evincing considerable interest as this polymeric materials help prevent environmental global warming. In this investigation two dissimilar ecofriendly polymers were blended by melt mixing in bra bender with particulate fillers to develop a thermoplastic elastomeric composite that was cured during compression molding to meet the demands of aerospace, automobile and other industries. The processed composites were assist for its strength and toughness. The fracture characteristics of tested sample were evaluated using ESEM

Experimental:
Material used:

Accelerators for rubber compounds — Accelerators for HDPE

Fabrication:

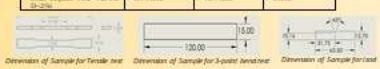
Cutting of composite panel in required dimension for mechanical testing
The 3D model was made using Solidworks software and saved as .dxf file format.

3DModeled Testing Sample
This .dxf file format was converted to .cdr format using CorelDRAW software.

After changing the file format from .dxf to .cdr the command was given to the laser cutting machine to cut the samples

Sample Dimensions as per standards

Test	Length	Width	Thickness
Tensile Test - ASTM D-412	165 mm	19mm	4mm
Flexure Test - Unnotched length- ISO-178-1993	120 mm	15mm	4mm
Izod Impact Test - ASTM D-256	63.5mm	12.7mm	4mm



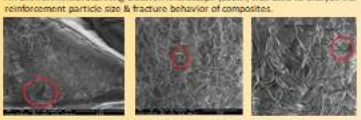
Mechanical Test results
Samples with 5, 10, 15, 20% EPDM balanced HDPE were processed and the test results are shown below

Tensile test
Tensile strength of EPDM & HDPE Composites tested as per ASTM D 412

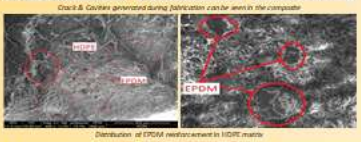
FLEXURE TEST (3 POINT BEND TEST)

Izod impact test

Fractography of tested samples
An Environmental Scanning Electron Microscope (ESEM) was used to analyze the reinforcement particle size & fracture behavior of composites.



Crack & Cavities generated during fabrication can be seen in the composite



Distribution of EPDM reinforcement in HDPE matrix

A colored view of impact fracture showing crack initiation and energy absorption during propagation

Results and Discussion
Test results indicate that with the increase in the amount of EPDM the impact resistance and absorption energy of the composites increases but tensile strength and flexure strength decrease. This may be attributed to the fact that EPDM is ductile material . The tensile Fractographs observed in ESEM are typical of two dissimilar polymers containing fillers that influence movement of viscous elastic polymer in highly crystalline linear molecular HDPE.. Impact fracture located near notch tip consists of crack initiation and propagation. High speed and triaxial stress at the notch tip show deformation bands that look like crazes in the form of river lines. At lower fracture speed the fracture morphology changes to dimples aligned in the crack propagation direction. The ESEM fractography indicates that to minimize the cavities & enhance mechanical properties of the composite mixture, the two roll mill mixing process should be done properly, with help of hot rollers.

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