ACCELERATED THERMAL CYCLING OF PRINTED CIRCUIT BOARD FOR SINGLE PHASE IMMERSION COOLING SYSTEMS

by

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Abstract

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The adoption of immersion cooling of data center over conventional air-cooling is one among the more up to date advances that individuals have begun embracing to. Acknowledgement of Single phase Liquid Immersion cooling (Sp-LIC) of Information Technology equipment gives proficient cooling frameworks and significant vitality energy savings. This study centers on the unwavering reliability assessment in analyzing the material property of Printed Circuit Board (PCB) and performing Scanning Electron Microscope (SEM) scanning of the samples for any penetration of liquids into PCB. The Accelerated Thermal Cycling (ATC) test in view of ATC JEDEC is relevant just for air cooling. The ASTM benchmark D3455 with some appropriate modification was adopted to test the material compatibility because of constraints with dielectric fluids. For this review, an accelerated thermal degradation of Printed Circuit Board submerged in air, mineral oil and synthetic fluid at a hoisted temperature of 45^{o}C and 35% humidity is proposed for prolonged period of time. Young's Modulus estimation was done on the Dynamic Mechanical Analyzer (DMA7100) machine. In this thesis, we have looked into the progressions in the physical property of PCB and outwardly investigated the part for any cracks because of Single phase Immersion Cooling. The samples experienced the same stress condition in air and mineral oil during the same time and experiment was performed for the mentioned properties to have a correlation in degradation patterns. The thermal

acceleration factors for the degradation might be founded on the design of tests enabling relative interference to be made based on air, mineral oil and synthetic fluid media on parameter corruption. This research determines the material compatibility of PCB's with respect to Single phase Immersion Cooling.

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Overview

Data centre is a mission critical facility that contains many information handling hardware, for example, servers, switches and switches [1]. All the information is handled through the data centre and is stored for later use. In the long run, data centre utilize half the power of the entire company. As the data centre does most troublesome undertakings, its segments likewise get warmed up effortlessly and high heating of these hardware isn't prescribed as it may harm the IT equipment which would cost the organization more as the work arrives at halt. As of late, there has been a blast in data centre utilization, driving its vitality utilization to develop by 10% a year constantly. To counteract this, cooling of the equipment is presented and the fundamental point is to center around the cooling of the hardware to keep the work going on and the running of the association. The heat produced ought to be expelled to keep high temperature from degrading their reliability.

Data centre air cooling method

In conventional sense, includes utilization of Computer Room Air Conditioners (CRAC) to change over hot air to cool air by expelling heat to the outside. One generally utilized approach is raised ground surface. CRAC supply cool air underneath the room and is attracted upward utilizing fans to cool servers. Hot air bearing warmth at that point rises and the CRAC gather it from higher up, cool it and return it. To give considerably more proficiency, a few plans execute hot aisles and cold aisles to segregate hot air from cool air. Server air inlets confront cool aisles and air outlet confront hot aisles.

The advantages to utilizing an air-cooled framework in a data centre are many. Cooling with air is all the more ecologically friendly, can extraordinarily bring down cooling costs, and is turned out to be more secure than numerous other cooling alternatives. Energy is saved in light of the fact that ventilating units don't need to always be running, and can be turned off for intervals with a specific end goal to preserve energy and save money.

With an air-cooled framework, the mechanical outlines keep water from coming through openings in the building, expanding the safety of the cooling framework. Air cooling frameworks likewise use channels to clean air from outside before it enters the building. Numerous frameworks for cooling that utilization air can likewise be adapted by using humidification. Every one of these components work to expand the security of the cooling systems as it cools the PC room and all your imperative equipment [2].

Energy used for Air cooling:

The Data centre is a major segment utilizing which a large portion of the work is done and because of this, enormous measure of heat is delivered which takes in loads of electrical power. This heat delivered by the server farms should be expelled which generally may harm the parts.

To evacuate this heat, cooling units must be utilized and this requires more electrical power. These cooling equipment when they take out the heat, must be cooled back to take out increasing heat which requires more energy. Consequently, the working expenses of the data centre are higher than the cost of development and are around equivalent to the measure of energy used and the amount of heat expulsion [3].

Fig 2.5 portrays the utilization of energy in billion kWhr/yr in the years 2000 and 2005. It demonstrates that the usage of energy altogether overall data centre has multiplied from 2000 to 2005. IT load takes up to 80 billion kWhr/yr of the aggregate vitality out of which just about 80% is devoured by assortment of servers like top of the line, mid-range and volume servers and around 10% is taken up by communications and another 10% for storage. Cooling equipment utilizes almost half of the energy accessible [4].

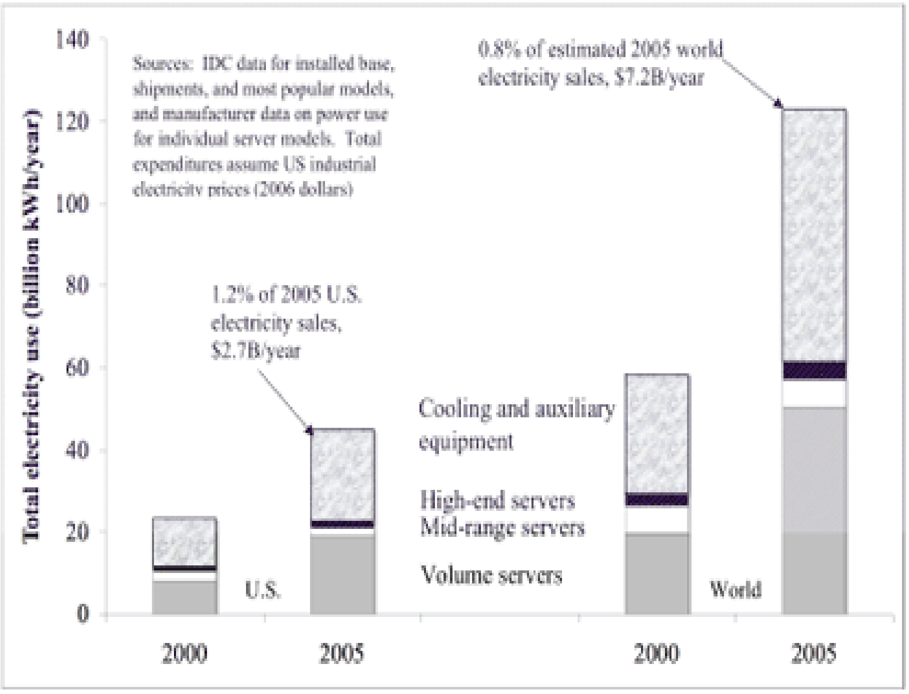


Fig 1-1: Utilization of energy in 2000 and 2005

Limitations of Air Cooling of Data centre

- Electricity is required for fans to move air through a server farm.
- Ventilated floor tiles are famous for confining air flow and giving the wrong measure of air to a given PC area.
- Raised floor tiles to distribute air are an unneeded cost, and they make inherent cooling issues.
- Air distribution through raised floor tiles makes static air force [18].

Advantages of Immersion Cooling of Data centre

- Eliminates need for elevated flooring.
- No need of server fans.
- No need for Computer Room Air Conditioner (CRAC) unit.
- Can save money on power bills.
- These immersive systems eliminate the need for air cooling and, due to their efficiency, also allow equipment to run at higher temperatures [17] [19] [21].

Problem Statement

The problem here is to understand the impact of synthetic fluid on the reliability and operability of Printed Circuit Board.

Approach

The two main features of our approach is as follows

- Thermal cycling
- Material testing and Analysis

Strategy

The plan of action designed to achieve our overall aim is as follows

- Evaluate change in physical property of samples after Accelerated Thermal Cycling (PCB immersed in synthetic fluid and maintained at 45^{o}C and 35% RH).
- Compare the values to the samples immersed in mineral oil and exposed to air.
- Investigate failure (if any) that occur in PCB.

Aim and objective

This paper aims at the reliability of Printed Circuit Board immersed in synthetic fluid and developing a correct methodology for experimentation. The objectives are stated below.

1) To focus on the understanding of the impact of synthetic oil immersion cooling on reliability of data centre component

2) To focus on developing a correct methodology for synthetic oil immersion cooling and plan for the procedure of the experiment.

3) Preparation of the samples that are required to test on the instruments for any change in properties.

4) To hypothesize the outcomes when the samples are made to undergo various number of cycles.

5) To evaluate the change in material properties (Young's modulus) after exposure to various cycles in synthetic oil.

We have prepared and baked the samples as per the modifications made to the standards. The environmental chamber used for this experiment is Thermotron SE-600-10-10. After each cycle, the specimens were taken out and the experiments were performed to record the changes in material properties, electrical performance and visual analysis for any cracks. The results of the experiments are discussed in this paper.

Introduction

As we all know that people have started adopting to newer technologies, older ones are at the verge of extinction. One such practice is the adoption of immersion cooling of data centre over conventional air-cooling of data centre. The former is supposed to be powerful, effective and cost-efficient. The submersion cooling innovation is the new worldview to illuminate the difficulties being related with the exponential development of information that is looked by cutting edge data server [5].

It is the practice of immersing the servers in a dielectric coolant. The fluid utilized must have adequately low electrical conductivity not to meddle with the ordinary task of the PC. In the event that the fluid is to some degree electrically conductive, it might be important to protect certain parts of segments vulnerable to electromagnetic obstruction. Hence, it is favored that the fluid be dielectric [6].

By submerging the majority of a server's warmth producing parts in a dielectric fluid, makes the assault on dependability issues at the gadget level. Dielectric fluids are not only used in computing and electric power applications but also in medical and domestic applications. In single phase immersion cooling, the dielectric fluid coolant dependably remains in liquid state (as opposed to the two-phase coolants that change state from liquid to gas and back). The coolant fluid is dependably in contact with the equipment introduced in the bath and is pumped through the equipment towards heat exchanging system that consider the extraction of heat gathered by the coolant. Single phase immersion cooling has the advantage of lower maintenance cost, lower coolant cost, absence of coolant evaporation and reduction in noise compared with air cooled data centre [7] [19].

The ideology from the paper "Design consideration related to non-thermal aspects of oil immersion cooling" can be used for maintenance and serviceability of the immersion cooled data centre as it does not hold any standard as air cooled data centre [8].

In this paper, we are going to assess the change in material properties (Young's modulus) and visual analysis for any cracks which decide the mechanical execution of PCB separately in the wake of cycling in synthetic oil in contrast with control tests in mineral oil and air. The fundamental thought is to assemble an assortment of information to enable industry to make more educated with respect to mechanical unwavering quality of IT hardware in synthetic oil immersed frameworks. Accelerated Thermal Cycle (ATC) test in light of 'ATC JEDEC' benchmarks which is utilized for air cooling has a few confinements. The ASTM standard D 3455 with some modification as required was adopted to test the material compatibility with the dielectric fluid. The modification to the standards implemented in this paper are: the dry run cycle was reduced to 8 hour at 30°C and 10 % RH, the baking time of the sample was reduced to 4 hour at 45°C and 35% RH, and the cycle time was reduced from 164 hour at 100°C to 72 hour at 45°C [9] [17] [20]. The degradation mechanism of the PCB specifically because of immersion in oil will be researched.

Printed Circuit Board

Printed Circuit Boards create the electronic circuits conventionally utilized as a part of the business. Glass reinforced plastic (FR4 type) produces the boards with the assistance of copper tracks in the place of wires. Active and passive components are settled in position by entering openings through the board, finding the parts and afterward affixing them in place. The copper tracks joins the components together, surrounding a circuit. Mounting the electrical parts on the printed circuit boards require an assembly process. This method ought to be possible by hand or through particular apparatus. The assembly process requires the usage of weld joint to put the components on the board [10]. PCB's have a normal stress/strain proportion of 12Gpa to 19Gpa depending upon the board producers. They can work between temperatures of - 50°C to 110°C [11].

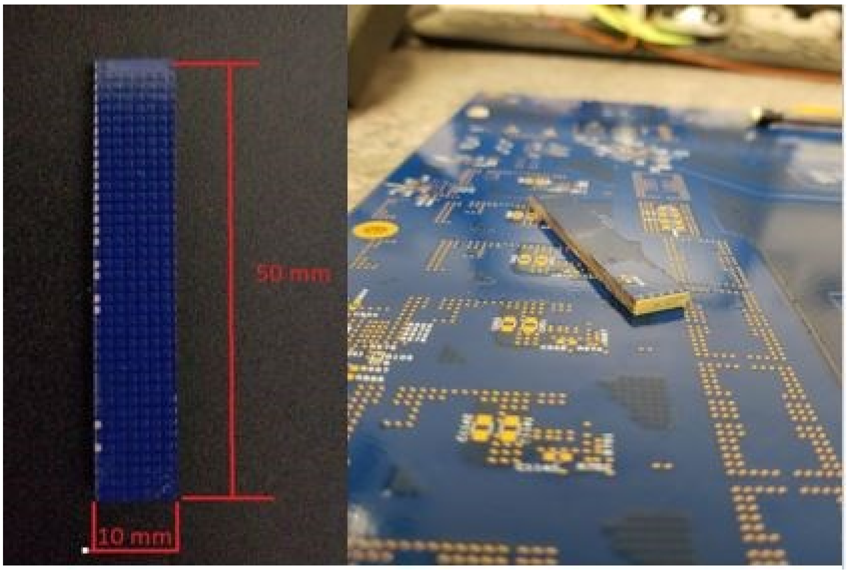


Fig 5-1: Sample of Printed Circuit Board for experiment

Thermal Cycling

Thermal cycling is a characteristic feature of all utilization of materials at elevated temperatures. Thermal cycling is one of the testing strategy most regularly used to assess the dependability of the electronic equipment. The components that influence the cycles which prompt the failure are typical to dwell, chill off and heating rates inside a given temperature run. Thermal degradation implies the chemical and physical methods in polymers that occur at higher temperatures. Raised temperature stimulates most of the ageing shapes that occur in polymers [12].

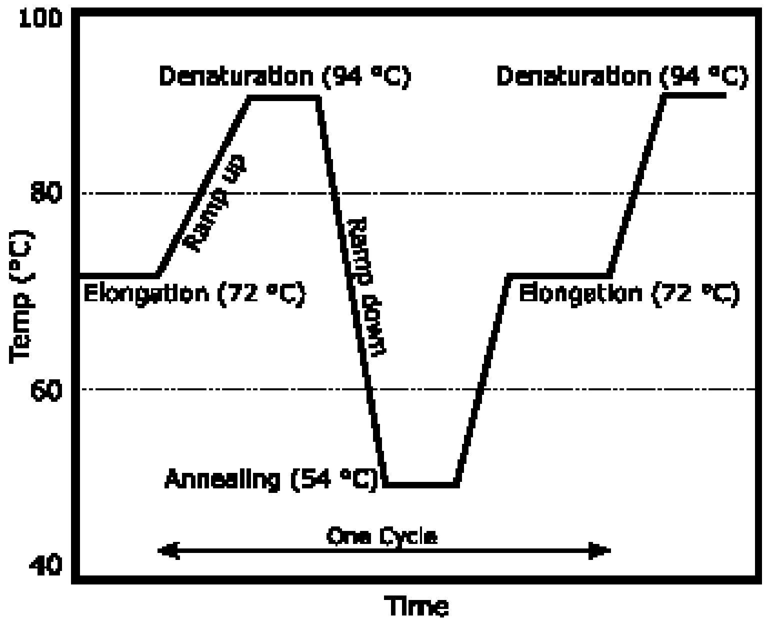


Fig 6-1: Thermal cycling test

Methodology

A printed circuit board consist of flat sheet of insulating material and a layer of copper foil, laminated to the substrate. Samples of PCB are prepared using Isomet 1000 precision cutter. Samples prepared using the cutter have a dimension of 50mm*10mm. The unknown elastic modulus of the sample is tested using the DMA machine. Firstly, the environmental chamber undergoes a dry run and immediately followed by the baking cycle. During the baking cycle, all the components placed inside the chamber has minimal contact with each other. After this cycle, two airtight Pyrex glasses are filled separately with 800ml of synthetic fluid and mineral oil. Then the samples of Printed Circuit Board are immersed into the fluid. First set of components are in the synthetic oil jar and the second set in mineral oil jar and enclosed the glass jar with an air tight lid. Similar set up is followed for optic fiber cables. Additionally, another set of all components with minimal point of contact were placed in a Pyrex glass open to environmental chamber conditions.

Now the fluid filled glasses are placed in the environmental chamber and the cycle is started. After 72 hours, a set of samples were taken out using tongs and stored in an air tight Aluminum covers after which the next cycle is started. Once the samples are taken out they are tested for the changes in their properties. For PCB, the young's modulus is experimentally found out using the DMA 7100 machine and the change in values are plotted in a graph. The results are discussed in this paper.

Instruments used

IsoMet 1000 Precision cutter

The IsoMet 1000 is an accuracy segmenting saw that is intended for cutting different kinds of materials with negligible deformation. This exactness cutting machine is perfect for fragile parts by just utilizing gravity fed force. Its extraordinary flexibility in throwing considers holding a wide range of test shapes and designs giving the present research center an exactness cutting machine fit for separating for all intents and purposes any material including fragile metals, composites, concretes, overlays, plastics, electronic gadgets, and bio materials [13].

Fig 8-1: IsoMet 1000 cutter

Environmental chamber

An environmental chamber, additionally called a climatic chamber or atmosphere chamber, is a fenced in area used to test the impacts of determined environmental conditions on organic things, mechanical items, materials, and electronic gadgets and segments. An environmental test chamber falsely duplicates conditions which hardware, materials, gadgets or parts may be presented to. It is additionally used to quicken the impacts of introduction to the environment, infrequently at conditions not really anticipated.

Chamber testing includes testing and presenting items to different natural conditions in a controlled setting. Climatic Chamber testing and Thermal Shock testing are a piece of chamber testing. Climatic Chamber testing is a wide term used to depict distinctive methods for recreating atmosphere or over the top encompassing conditions introduction for an item or a material under research centre controlled yet quickened conditions. Then again, Thermal Shock testing is utilized to recreate how materials will respond when presented to changes in outrageous climatic conditions, for example, going from greatly chilly to a great degree hot conditions in a brief timeframe.

The environmental chamber used here is Thermotron SE-600-10-10. The features of the chamber mentioned are as follows.

- The window sizes for all SE Environmental Chambers are 15 x 19 inches / 38 x 48cm. Custom window sizes are available.
- Temperature Control: ±0.3ºC (±0.5ºF). Standard deviation from mean, measured at -25°C (-13°F) or 100°C (212°F).
- Air temperature is measured with an empty climatic chamber
- All SE-600 Environmental Chambers are tested with 50 lbs/23 kg aluminum sheets.
- Climatic Chamber performance is based upon laboratory ambient conditions of 23.9°C, and may vary slightly [14].

Fig 8-2: Thermotron SE-600-10-10 Environmental Chamber

Dynamic Mechanical Analyzer

With its excellent general execution and easy to use outline, the DMA7100 is perfect for uses from normal and high-level research. A navigation control in the product and the natural sample clamping design allow for straightforward activity. The highlights of DMA7100 are as per the following.

- Highly reliable measurement by Lissajous monitor.
- Easy operation with interactive software and user friendly sample loading design.
- More economical cooling unit.
- Sample observation option (Real view DMA) [15].

Fig 8-3: DMA 7100

Scanning Electron Microscope

The Scanning Electron Microscope (SEM) utilizes an engaged light emission energy electrons to produce an assortment of signs at the surface of strong specimens. The signs that get from electron-test co-operations uncover data about the sample including outer morphology (surface), concoction composition, and crystalline structure and introduction of materials making up the sample. In many applications, information are gathered over a chosen area of the surface of the sample, and a 2-dimensional picture is produced that showcases spatial variations in these properties. Areas running from around 1 cm to 5 microns in width can be imaged in a scanning mode utilizing ordinary SEM systems (magnification going from 20X to roughly 30,000X, spatial resolution of 50 to 100 nm) [16].

Fig 8-4: Scanning Electron Microscope S-3000N

Single phase Liquid Immersion Cooling fluids

Mineral Oil:

Fig 9-1: Pyrex jars containing Mineral Oil

Synthetic fluid:

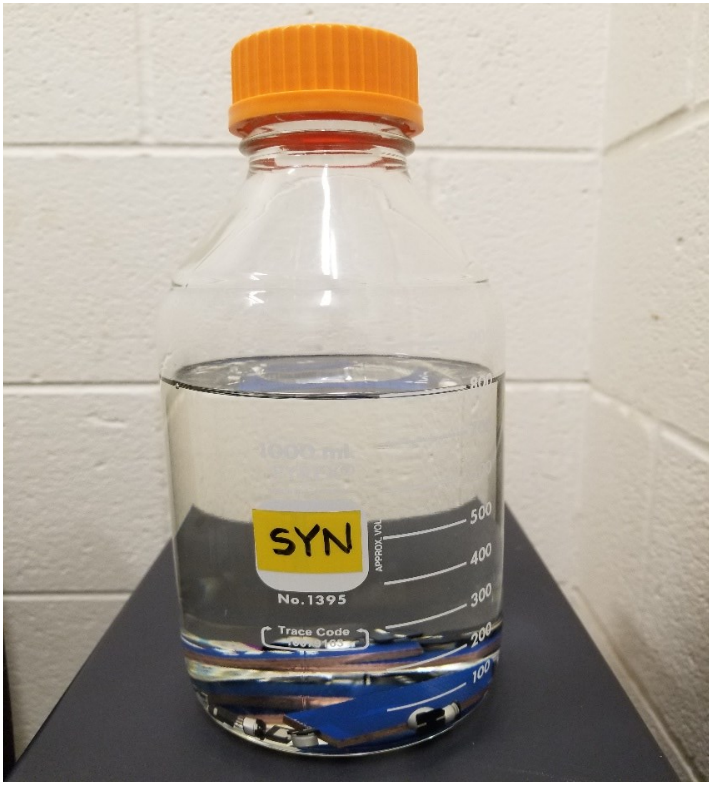


Fig 9-2: Pyrex jar containing Synthetic oil

Experimental setup

The environmental chamber used in this experiment is Thermotron SE-600-10-10. ATC JEDEC is the standard used for air cooling of Data Centre. The modifications made to the ASTM D3455 are as follows.

- Dry run of the chamber is modified to 30°C and 10% RH for 8 hours
- Baking cycle of the samples is modified to 45°C and 10% RH for 4 hours with minimal point of contact.

After baking, 2 Pyrex glasses are filled with 800ml of synthetic fluid and mineral oil, then the baked samples are immersed into the glass jars and closed with air tight lid. Another Pyrex glass jar only with the baked samples is left exposed to air. Thermal cycling conditions are as follows.

- Temperature : 45°C
- Humidity : 35%
- Cycle time : 72 hours
- No of cycles : 4

Fig 10-1: Thermal cycling setup inside the Thermotron chamber

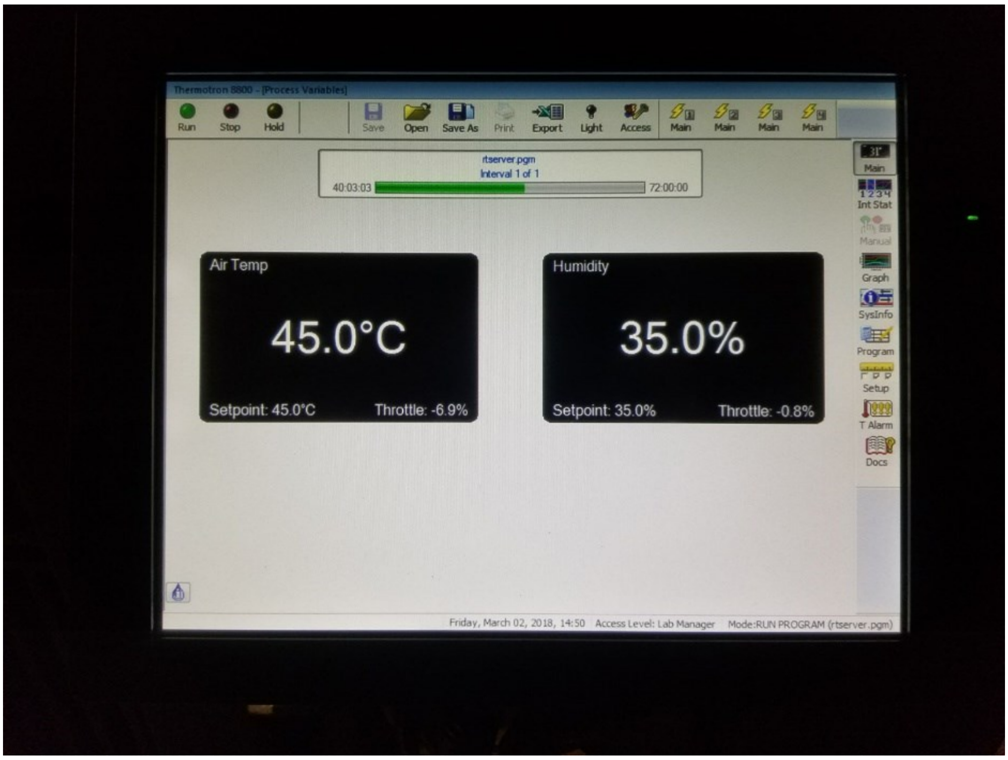


Fig 10-2: Thermotron interface

Working conditions of DMA7100

Young’s Modulus of the samples of PCB can be measured using DMA machine at various conditions of temperature and frequency. The conditions of DMA machine are as follows.

- Frequency – 1Hz, 2Hz, 5Hz, 10Hz
- Temperature – 30^{o}C – 50^{o}C
- Run time – 30 minutes/sample

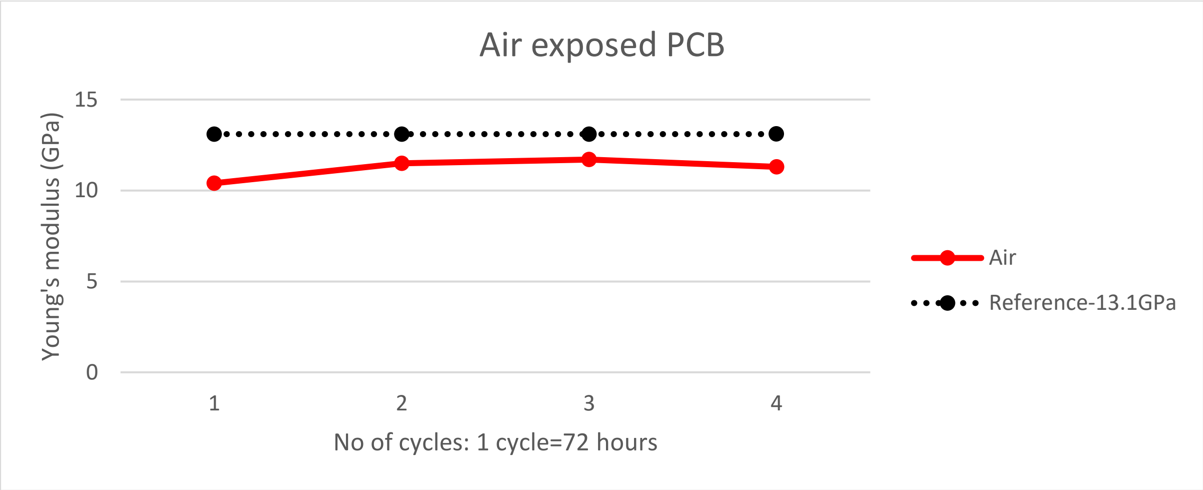
Physical property measured for Printed Circuit Board

Table 12-1: Young’s Modulus measured for various cases

Cycle	**Air exposed PCB**	**Mineral oil immersed PCB**	**Synthetic fluid immersed PCB**	**Reference value(Measured before experiment)**
	Young’s Modulus (GPa)			
Cycle1: 72 hours	10.5	9.5	9.9	13.1
Cycle2: 144 hours	11.5	10.3	11.2	13.1
Cycle3: 216 hours	11.7	10.8	10.7	13.1
Cycle4: 288 hours	11.3	12.4	12.8	13.1

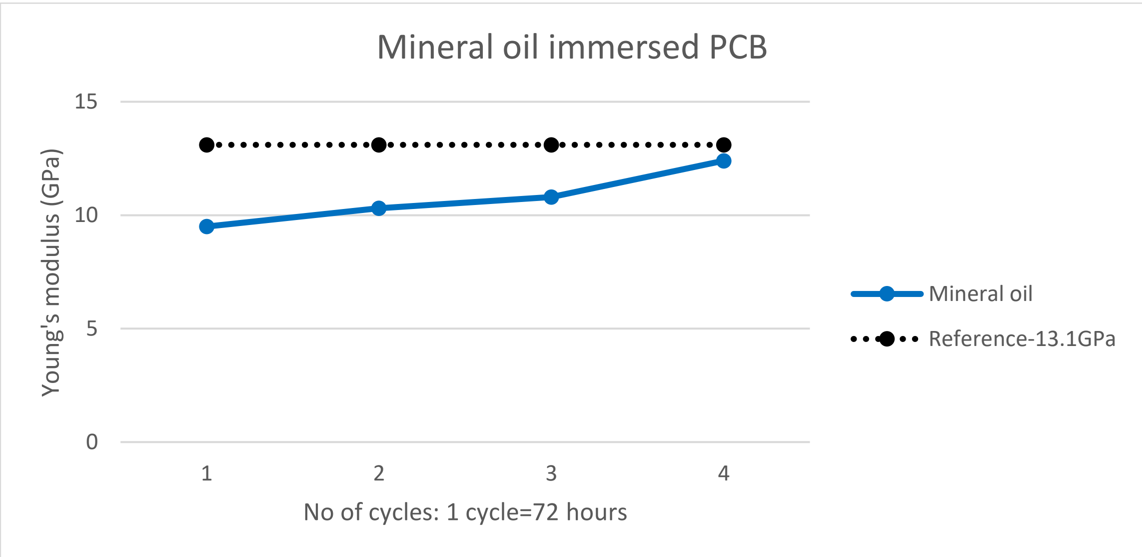
Graphical representation

Graph 1



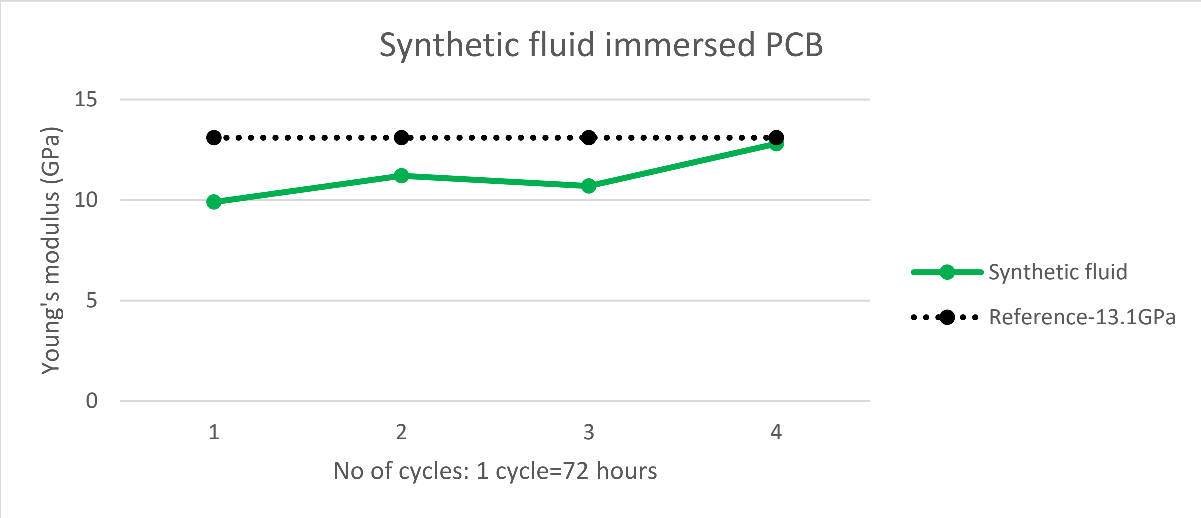
Young's Modulus vs No of cycles

Graph 2:



Young's Modulus vs No of cycles

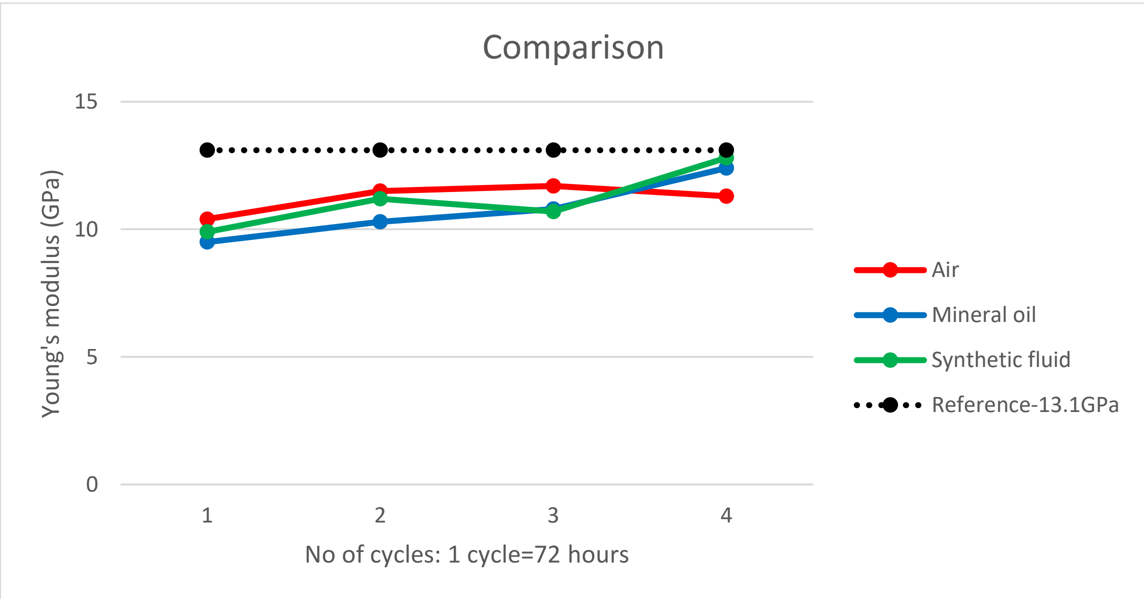
Graph 3:



Young's Modulus vs No of cycles

Graph 4:

Air-Exposed PCB vs Mineral oil immersed PCB vs Synthetic fluid immersed PCB



Young's Modulus vs No of cycles

Sample preparation of PCB for Scanning Electron Microscope

A Scanning Electron Microscope (SEM), like a transmission electron microscope, comprises of an electron optical segment, a vacuum framework, electronics, and programming. The column is extensively shorter because the lenses required are those over the sample used to focus the electrons into a fine spot on the sample surface. The sample chamber, be that as it may, is bigger because the SEM method does not force any confinement on sample size other than chamber size.

The electron gun at the highest point of the segment creates an electron beam that is engaged into a fine spot as little as 1 nm in distance across on the sample surface. This beam is scanned in a rectangular raster over the sample and the forces of different signals made by communications between the beam electrons and the sample are estimated and put away in PC memory. The stored qualities are then mapped as varieties in brightness on the picture display. The Secondary Electron (SE) signal is the most as often as possible utilized signal. It fluctuates with the geology of the sample surface much like an aerial photograph: edges are bright, recesses are dull. The proportion of the measure of the displayed picture to the extent of the area examined on the sample gives the magnification.

Cross-sectioning of the samples of PCB for SEM scanning was done using IsoMet 1000 precision cutter as per its requirements. The specifications of SEM for the scan are as follows.

- Vacuum pressure : 30 kPa
- Beam Current : 25 kV
- Working distance : 15-25 mm

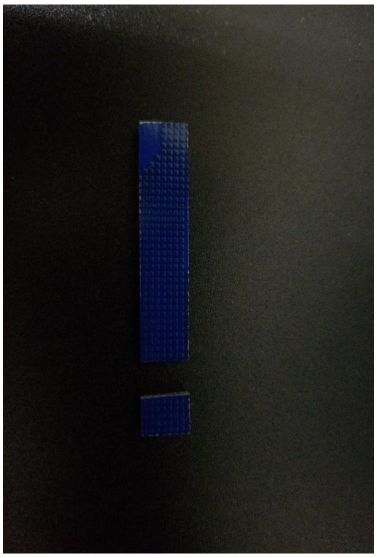


Fig 14-1: Cross sectioning of the sample of PCB

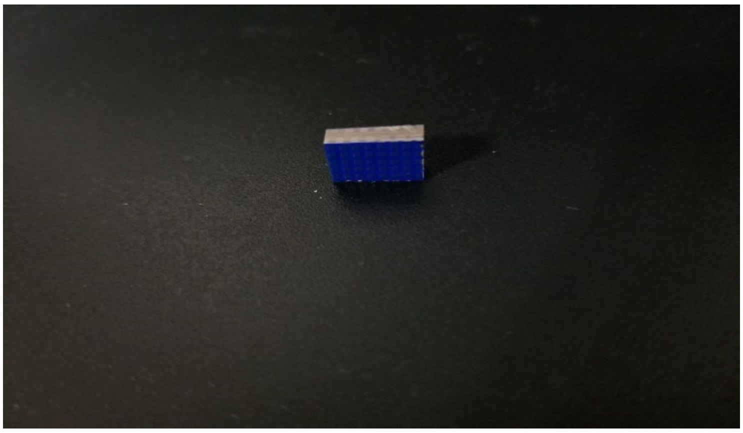


Fig 14-2: Sample used for SEM

SEM analysis for Mineral oil immersed PCB

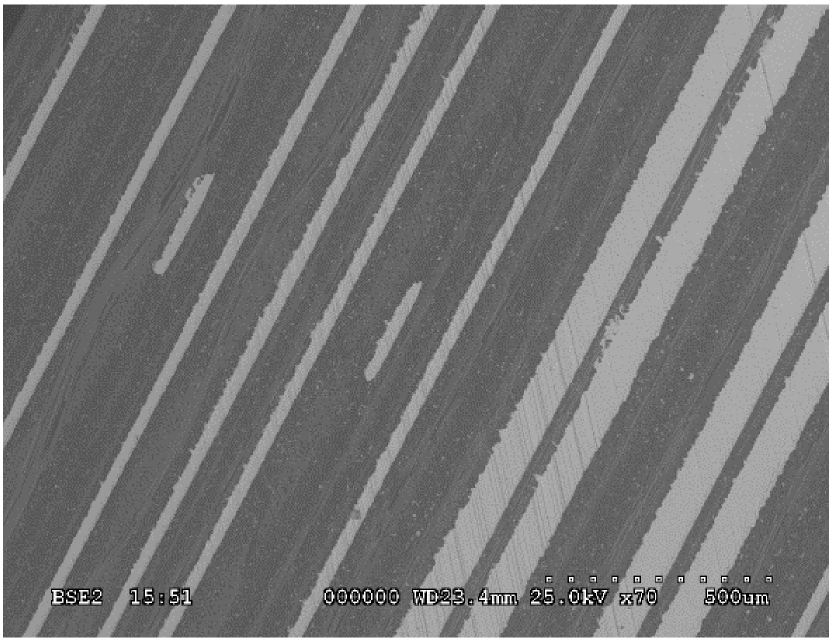


Fig 14-3: A – Spot 1

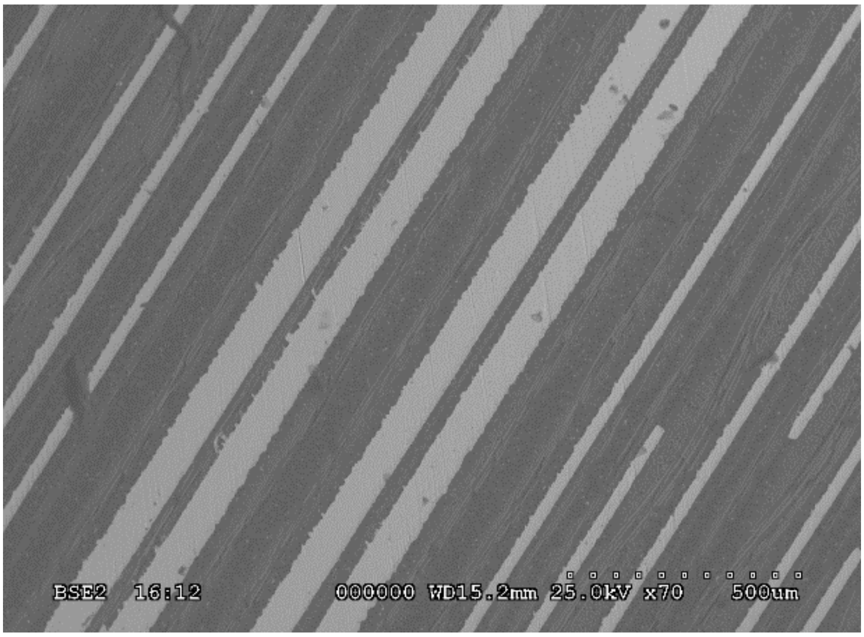


Fig 14-4: B – Spot 2

Sample taken after 216 hours (A, B)

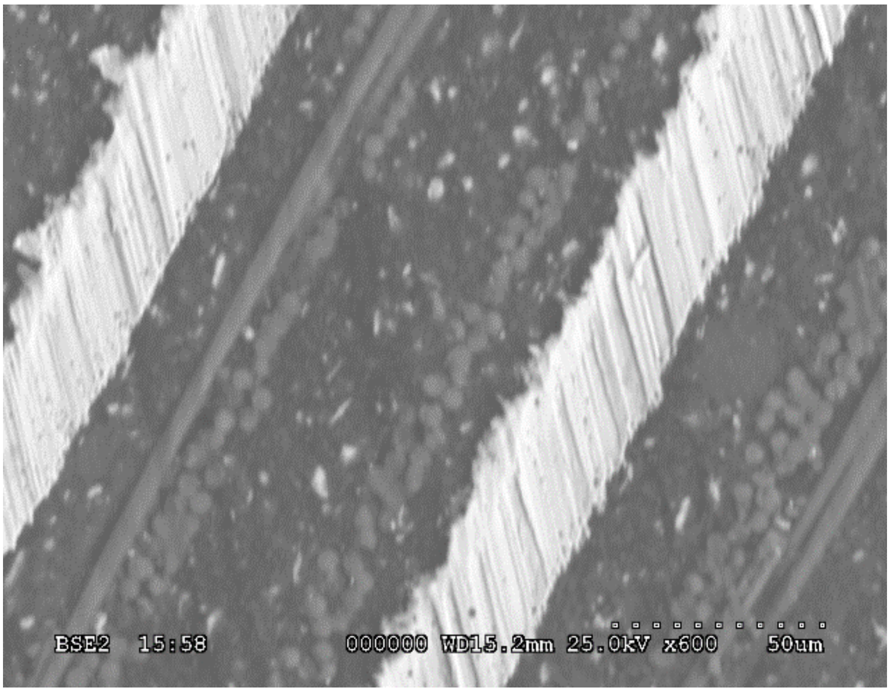


Fig 14-5: C – Spot 1

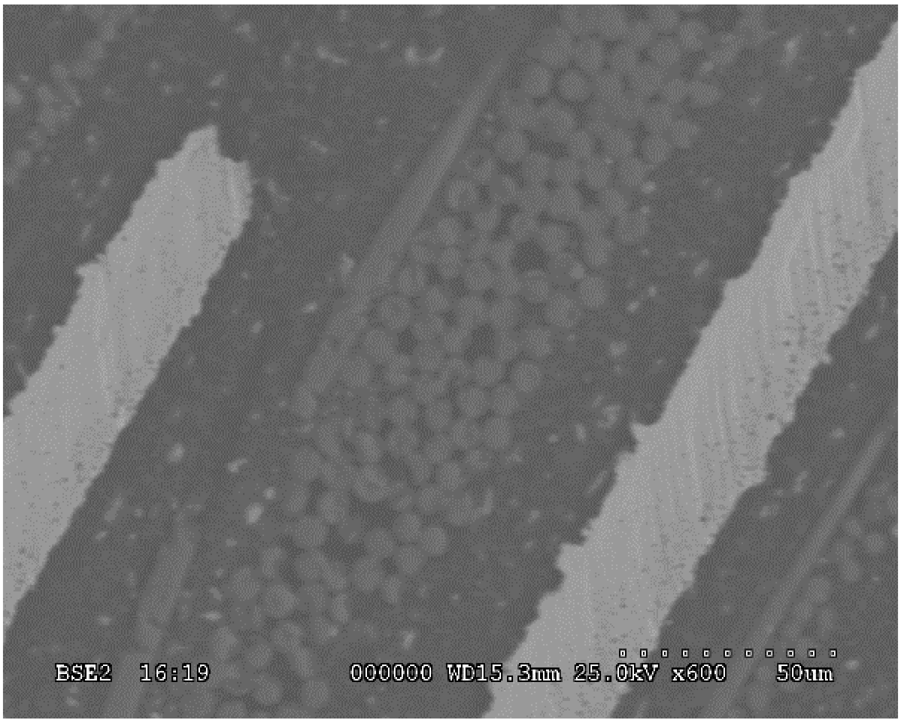


Fig 14-6: D – Spot 2

Sample taken after 288 hours (C, D)

SEM analysis for Synthetic fluid immersed PCB

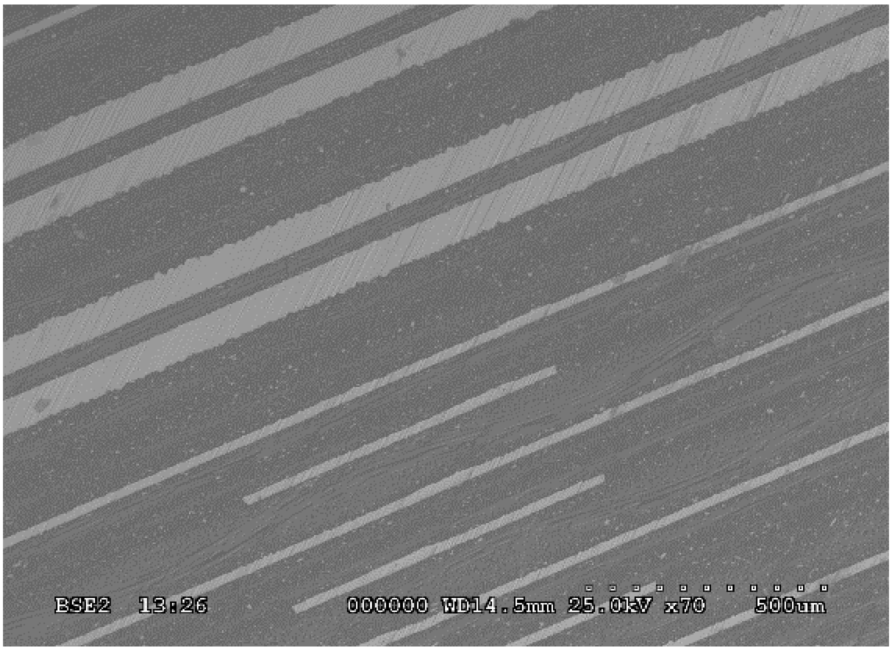


Fig 14-7: A – Spot 1

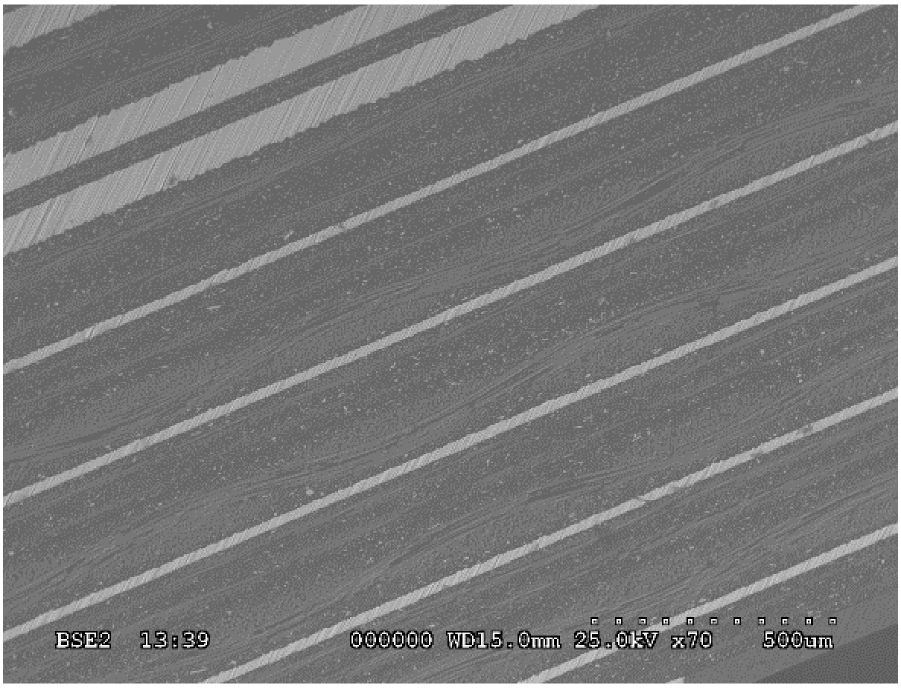


Fig 14-8: B – Spot 2

Sample taken after 216 hours (A, B)

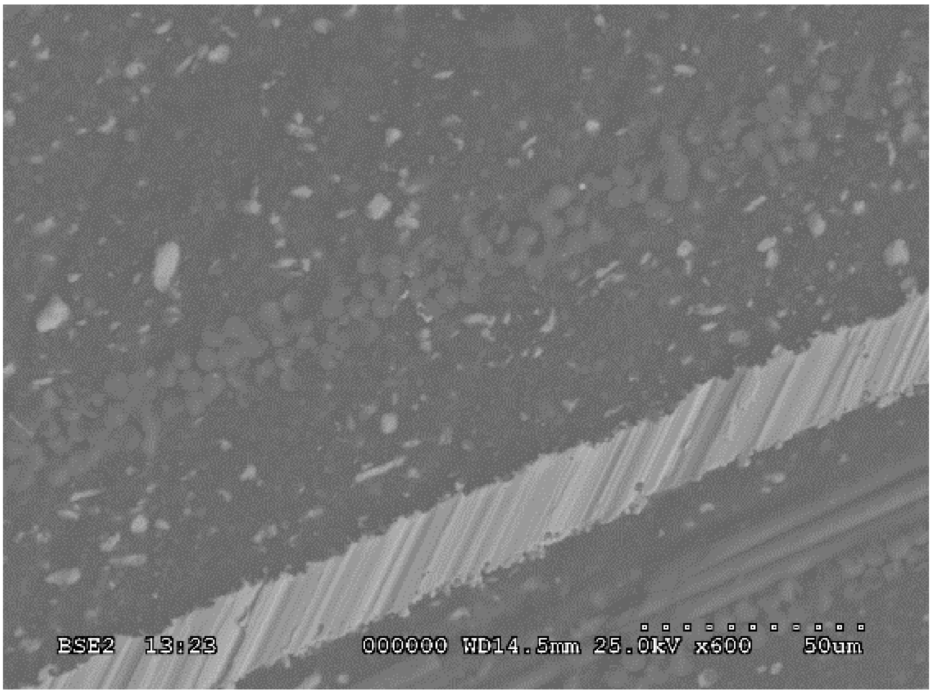


Fig 14-9: C – Spot 1

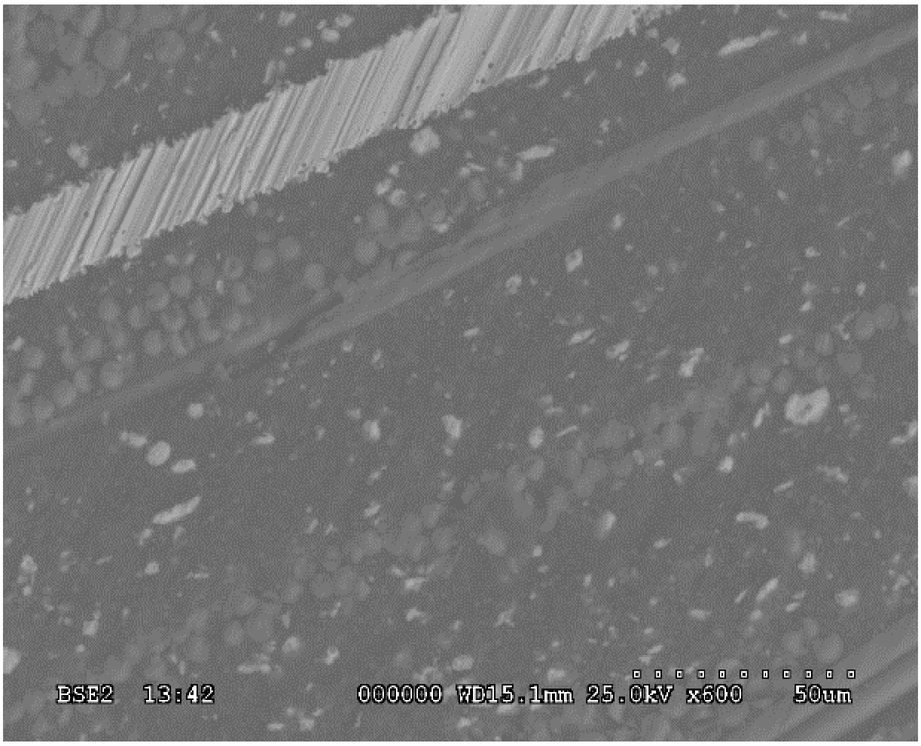


Fig 14-10: D – Spot 2

Sample taken after 288 hours (C, D)

Conclusion

- The change in physical property of the samples cooled by immersing in synthetic fluid is well in allowable range of Printed Circuit Board. We can conclude that there is no high variation in the mechanical property of PCB after long time at elevated temperature. We can at least mention that there is low Young's Modulus in all cases.
- At the end of life, at the very least, using this fluid is even or better. So, the single phase dielectric fluid used in the experiment seems to be as reliable as air and mineral oil for the application of cooling of data centre.
- SEM study shows that there is no formation of cracks or penetration in the Printed Circuit Board. The structural integrity is not disturbed.
- In terms of component reliability, this study has not indicated any reason for concern in Printed Circuit Board when immersing servers in different dielectric fluids. Reliability is not mitigated at the end of life.

Reference

[1] webopedia.com

[2] http://www.datacenterjournal.com/basics-of-data-center-cooling/

[3] Barroso, L.A. and U. Hölzle. "The data centre as a computer: An introduction to the design of warehouse-scale machines. Synthesis Lectures on Computer Architecture." 2009. 4(1): p. 1-108.

[4] Kota Venkata Naga Indu Sravani. “Development of a methodology and sample preparation to evaluate Reliability of Oil cooled data centre.” 2015

[5] Fujitsu Liquid Immersion Cooling System from https://www.fujitsu.com/global/Images/fujitsu-liquid-immersion-cooling-system-brochure.pdf

[6] What is Immersion Cooling, 2015, from https://submer.com/what-is-immersion-cooling/?

[7] Open Bath Immersion Cooling, 2015, from https://submer.com/open-bath-immersion-cooling/

[8] Jimil M.Shah, Syed Haider I. Rizvi, Indu Sravani Kota, Sahithi Reddy Nagilla, Dhaval Thakkar and Dr. Dereje Agonafer. “The Design Consideration Related to Non-Thermal aspects of Oil Immersion Cooling.” IMECE2016-67320

[9] ASTM D 3455-02 “Standard Test Method for Compatibility of Construction Material with Electrical Insulation Oil of Petroleum Origin”.

[10] Nilesh R. Bhavsar, H. P. Shinde, Mahesh Bhat. “Determination of Mechanical properties of PCB.” IJMER ISSN (Print): 2321-5747, Volume-2, Issue-4,2014

[11] Unique Rahangdale, R Srinivas, S Krishnamurthy, Pavan Rajmane, Abel Misrak, Dereje Agonafer “Effect of PCB thickness on solder joint reliability of Quad Flat no-lead assembly under Power Cycling and Thermal Cycling” SEMI-THERM, 33rd Symposium 2017

[12] Unique Rahangdale, B Conjeevaram, Aniruddha Doiphode, Pavan Rajmane, Abel Misrak, Dereje Agonafer “Solder ball reliability assessment of WLCSP—Power cycling versus thermal cycling” IEEE International Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm), 2017

[13] https://www.buehler.com/isoMet-1000-precision-cutter.php

[14] http://thermotron.com/se-600-10-10.html

[15] https://www.hitachi-hightech.com/global/product_detail/?pn=ana-dma7100

[16] https://www.fei.com/introduction-to-electron-microscopy/sem/

[17] J. M. Shah, R. Eiland, A. Siddarth and D. Agonafer, "Effects of mineral oil immersion cooling on IT equipment reliability and reliability enhancements to data center operations," *2016 15th IEEE*

Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm), Las Vegas, NV, 2016, pp. 316-325. doi: 10.1109/ITHERM.2016.7517566

[18] Singh P, Klein L, Agonafer D, Shah JM, Pujara KD. “Effect of Relative Humidity, Temperature and Gaseous and Particulate Contaminations on Information Technology Equipment Reliability.” ASME. International Electronic Packaging Technical Conference and Exhibition, Volume 1: Thermal Management ():V001T09A015. doi:10.1115/IPACK2015-48176.

[19] J. Shah et al., "Critical non-thermal consideration for oil cooled data-center" in IMAPS ATW 2015, Los Gatos, Ca, 2015.

[20] Jimil M. Shah, Dereje Agonafer, "Issue on Operational Efficiency for Oil Immersion Cooled Data Centers" in Session Co- Chair and Presenter for ASME Panel On “Thermal Management Challenges in Energy Conversion & Conservation” ASME IMECE 2015, Houston, Texas.

[21] Jimil M. Shah, "Reliability challenges in airside economization and oil immersion cooling", *The University of Texas at Arlington*, May 2016.

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