International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 09 Issue: 06 | Jun 2022 www.irjet.net p-ISSN: 2395-0072

Root Cause Analysis of Glass Fading Issue in Automotive Headlamp and Remedies for Failure Prevention

Ikhlas Chandkoti[1], Amol Naikwadi[2*], Manoj Mali[3], Srikanth T. S.[4]

[1,2,3,4] *Minda Industries Limited, CREAT Division, Pune-India.*

Abstract –

Visibility of the headlamp outer lens is commonly affected by haziness, fogginess, fading, or white patches caused by the deposition of volatile organic compounds, oxidation, chemical attack, water vapors, flying debris, and dirt. In the present research, two-wheeler headlamp with glass fading issues were identified and potential preventions have been discussed. Many of the headlamp outer lens is fabricated using glass material and outer lens glass fading is generally caused by the deposition of lower molecular weight moieties and lower temperature thermally unstable compounds. For this attempt, two-wheeler headlamp assembly was dismantled and characterized for possible root cause analysis and failure prevention. Different parts of the headlamp assembly such as reflector paint, bulb shield paint, dust cap, and housing were analyzed for thermal and morphological analysis. Thermal stability of the components was analyzed using thermogravimetric analysis (TGA). Morphological analysis was characterized by using scanning electron microscopy (SEM) and optical microscopy to evaluate the elemental alternation after deposition onto the outer lens. In house petri dish thermal box set up was prepared to evaluate the release of the lower temperature volatile organic compounds (VOC). The bulb shield paint system consists of filers, extenders, biocides, and lower molecular moieties for properties enhancement. The liberation of the lower molecular weight components and their deposition onto the inside layer of the glass outer lens resulted in the glass fading issue. The failure in the headlamp components was identified and remedies have been implemented for the failure prevention in future headlamp parts.

Key Words: Headlamp, Root Cause, Glass Fade, Volatile Organic Compounds, Protective Paint, Bulb Shield Paint, Failure Prevention

1. INTRODUCTION

The recent developments in the automotive sectors, industrial sectors, and building sectors have gained the researchers attention towards the drover safety concerns. Electric vehicles, driverless cars, hydrogen fuel cells are the recent advancements in the worldwide automotive sector [1-2]. Headlamp is one of the most important features in automotive industry. Two-wheeler vehicle headlamp consist of many different parts such as outer lens, housings, dust caps, reflector, bulb shield, and casings. The light illuminated by the lens provide the driver more visibility on road while driving at night and low sun light conditions [3]. Majority of headlamp outer lens are fabricated using glass and polycarbonate materials. When light emits through the headlamp lens it passes through the two different surfaces first one is the own lens glass and the second one is the headlight outer lens which is generally made up of glass [4]. In addition to these advantages, the outer lens' transparency is a critical aspect in preventing accidents during the night, rainy, and foggy seasons. Glass material is having excellent transparency and can withstand higher thermal stability but possess lower impact strength. In the recent years, researchers have developed the alternate material for the glass outer lens. There are severe concerns of glass outer lens as when impacted with sudden load glass material shattered and can cause serious injury to the drivers [5-7]. In comparison with polycarbonate material, glass material has good UV stability and scratch resistance and hence some of two-wheeler makers have requirements for glass outer lens material [8]. Polycarbonate polymers is having excellent impact strength, scratch resistance, recyclability, lower cost, better processability and light weight [9-10].

Accelerated change in technology, construction, and manufacturing sectors lead to an increase in ambient temperature, emissions, toxic gas pollution, and climatic circumstances [11]. Headlamp visibility and transparency can be impacted by many factors. These factors include as water vapor stuck into the headlamp assembly, dirt deposition onto inside or outside layer of outer lens, fog accumulation during extreme weathering conditions, white patches due to sudden load or impact, or fading issue due to deposition of gases or chemicals glass material [12-13].

The outside surface of the lenses can be damaged by a variety of environmental factors as well as manual interference, whereas the inside surface of the lenses can be chemically attacked due to the release and deposition of volatile organic compounds (VOC) [14-15]. In the glass outer lens, glass fading and haziness are majorly observed failures due to the deposition of lower molecular weight compounds onto the inside layer of the headlamp outer lamp which resulted in the reduction in the transparency [16]. On the other hand, dirt and mud particles accumulated on the outer lenses, reducing the visibility and transparency of the outer lens material [17]. The volatile organic compounds (VOC) deposition onto the inside surface of the outer lens is major concerns due to release and deposition of lower molecular weight compounds from the other plastic parts like dust caps, reflectors, shield pant, and housings etc. Headlamp in on condition generate the heat more than 120 °C which is responsible for the release of volatiles present in the plastic or paint system [18].

In the present work, we have found out the possible root causes for glass fading issues observed in the headlamp. **Figure 1** shows the photographs of glass faded outer lens, reflector paint and bulb shied paint Minda industries are leading original equipment manufacturer of automotive components. The glass fading issue was observed in the headlamp outer lens and several experiments were implemented to find out the root causes for the failure prevention. In order to avoid this kind of glass fading we have carefully observed the individual headlamp component more over polymeric material, which has possibility to release the volatile gases. Table 1 shows the different components of the headlamp assembly along with fabrication material. We have done the petri dish thermal box test of the individual headlamp component to observe any release of gases from the plastic parts mounted onto the backside of the lens. Differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA) has been done in order to confirm the gases released from child parts like. We have also run the SEM-EDS analysis to check the ash recovered from the TGA analysis for better understanding on the filler side.

Table 1: Components of headlamp and their fabrication materials.

S.N.	Description	Material
1	Reflector	Polyphenylene Sulphide (PPS)
2	Light Guide	Polymethyl Methacrylate (PMMA) HT
3	Bezel	Polyphenylene Sulphide (PPS)
4	Dust Cap	Silicon Rubber
5	Bulb Shield	CRCA (Nickel Chrome Plated)
6	Grommet	Silicon Rubber
7	Breather Sticker Type	Nitto Denco Sticker (Atlanta)
8	O ring	Nitrile Butadiene Rubber (NBR Black)
9	Washer	Nylon 66
10	Two Part Sealant	Epoxy Resin
11	Potting	Epoxy Resin
12	Washer	Nylon 66

1.1 Experiments

Materials and Methods:

Two-wheeler headlamps obtained from Minda-Rinder Industries Pune, India. The obtained headlamp was complete assembly with glass fading issue. Isopropyl alcohol (IPA) was used to clean the sample pans of DSC, TGA and optical microscopy platform was purchased from Loba Chemicals, India. Nitrile hand gloves were used to eliminate the direct contact with samples were purchased form Swati Scientific, India.

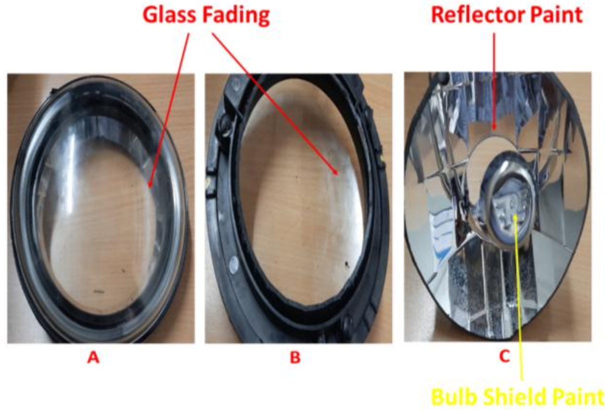

Figure 1: Headlamp assembly components (A) Outer Lens, (B) Inner Lens (C) Reflector Paint and Bulb Shield Paint.

Methods:

The main aim of the experiment is to check whether the glass fading caused by the individual parts or number of parts are releasing gases due to heating. Because glass fading can reduce the glare with reducing the visibility of the outer lens. The complete headlamp assembly was dismantled into outer lens, dust caps, housings, reflector, and bulb shield. The dismantled components were characterized for petri dish thermal box test at 180°C for 4 h. In the petridish test, it was observed that bulb shield paint system releasing some volatile compounds and deposited onto the inside layer of the petri dish. The schematic representation of the bulb shield paint petri dish sample is shown in **Figure 2.** In order to confirm the volatile organic compounds releasing from the bulb shield paint, we have carried out thermal and morphological characterization using thermogravimetric analysis (TGA), differential scanning calorimetry (DSC), scanning electron microscopy (SEM) and optical microscopy.

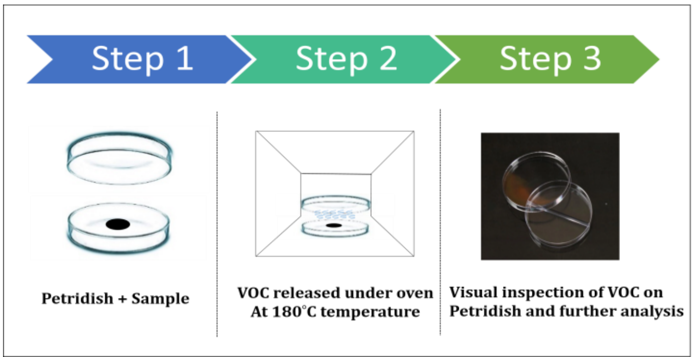

Figure 2: Schematic representation of petri dish thermal box test

2. Material Characterization

2.1 Optical Microscope

Optical microscope analysis is employed to check the morphological behavior bulb shield paint sample after the petri dish thermal box test. Optical microscopy is a nondestructive testing used to analyses the surface morphology. The optical microscope, also referred to as a light microscope, is a type of microscope that commonly uses visible light and a system of lenses to generate magnified images of small objects. Leica DM2700 model has been used for analysing the petri dish to check the deposited layer.

2.2 Thermogravimetric Analysis (TGA)

Thermogravimetric analysis is applied to check any kind of volatile organic compound release (VOC). Thermogravimetric analysis (TGA) is destructive technique used to determine a material's thermal stability and its fraction of volatile components by monitoring the weight change that occurs as a sample is heated at a constant rate. The thermogravimetric analysis of bulb shield paint and reflector paint was obtained with TA make instrument TGA 55 (Serial Number: 791). We have run the TGA in presence of nitrogen purging. Test Parameters: Heating from 25 °C to 200 °C with the heating rate of 20 °C/min. The test was maintained at 200 °C for 1 h using isothermal mode.

2.3 Differential Scanning Calorimetry (DSC)

DSC is used to analyze the thermal properties of the bulb shield paint and reflector paint. Also, release of any low temperature volatiles or any other regrind mix with the base material was analyzed using DSC analysis. Differential Scanning Calorimetry (DSC) is a thermal analysis technique in which the quantification of heat flow is measured as a function of time or as a function of time at a given temperature. DSC of bulb shield paint and reflector paint is obtained with TA make instrument DSC 25 (Serial No 1152). We have carried out DSC analysis in the presence of nitrogen atmosphere. Test parameters: First heating from 40 °C to 300 °C isothermal for 3 min cooling from 300 °C to 40 °C. Second heating from 40 °C to 300 °C isothermal for 1 min. Sometimes during first heating, some erroneous peaks appear resembling to the releasing of volatile compounds due to moisture absorbed by polymers or any other low molecular weight components presents in the polymers. In the second heating cycle, these peaks were got diminished.

2.4 Petri dish thermal box test

This petri dish thermal box test is house made setup. In this test two petri dish were used for the analysis along with the thermal box. Bulb shield paint and reflector paint was scratched out form the surface and kept into the first petri dish and covered with second petri dish. This petri dish was then kept inside the thermal box and test was carried at 180 °C for 4 h. Visual inspection was carried out to observe the deposition of any lower temperature volatile organic compounds. All the components of the headlamps were analyzed using petri dish thermal box test.

2.5 Scanning Electron Microscope (SEM)

Scanning Electron Microscope is highly sophisticated analytical technique often use to analyze the die/package cracks, fracture surfaces, bond failure, physical defects which is all related to the surface morphology. SEM analysis is a powerful analytical tool, which uses a focused beam of electrons to produce complex, high magnification images of a sample's surface topography. How small the size of electron beam shot into the specimen can get is the key to high resolution of SEM. Metal sample can directly place onto the mounting stab. Both sided carbon tape is used to fix the sample with the sample-holding stab. Polymeric samples cannot use directly as polymers are nonconductive material which accumulate the static electric field and starts charging. To prevent the charging of the sample ultrathin coating of gold, silver, platinum, chromium is done onto the sample, which is called sputter coating. We have used the latest model of JEOL make SEM (IT-200) (Serial Number: MP1040003050305) which has a unique feature of low vacuum mode which prevents the polymeric samples from charging even if you are using without sputter coating. Both sided carbon tape is used to fix the sample onto the sample-holding stab. Sample is carefully blown out to remove any dirt and dust particles, Height is measured to avoid any breakdown issue and successfully mounted onto the specimen chamber stage.

3. RESULTS AND DISCUSSIONS

3.1 Optical Microscopy Analysis

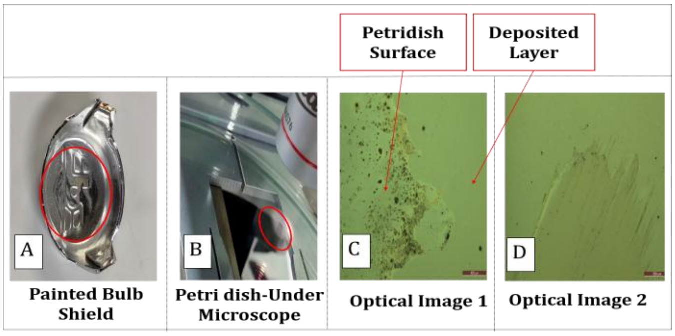

Figure 3: Optical Microscopic Imaging (A) Painted Bulb Shield (B) Petri dish Under Microscope (C) Optical Image 1 (D) Optical Image 2

Morphological analysis of the paint coated bulb shield samples and petri dish samples were carried out using optical microcopy. Optical microscopy test was employed to check the surface roughness of the petri dish after the heating and VOC deposition. Along with the petri dish, painted bulb shied surface was also captured using optical microscopy. The glass fading in headlamp is majorly due to deposition of the VOC onto inside surface of the headlamp. It was difficult to put the headlamp for optical microscopy test hence we have taken some of the scratch out some of the painted material and kept it into petri dish. Further, the petri dish was heated about 180 °C for 4 h. The lower temperature VOC got deposited and tested for optical microscopy. Figure 3 (C) and (D) demonstrates the optical microscopy images of the petri dish after heating at 180°C. It can be seen from Figure 3 (C), surface roughness with some black marks are observed which signifies that some gases were released during heating process and got deposited onto the inside surface of the glass headlamp and fading was observed. Figure 3 (d) shows the micrographs of the petri dish sample after heating process with 5 g of sample and checked the gases deposition onto the petri dish layer. It was observed that with highest amount of material the gas released at lower temperature got deposited and formed the uniform layer onto the inside surface of the petri dish and fading was noticed. Figure 3 (B) displays the petri dish under the microscope lens. Further this VOC released was confirmed by TGA and DSC analysis.

3.2 Thermogravimetric Analysis (TGA)

Thermal stability of the reflector paint and bulb shield paint was determine using thermogravimetric analysis. As from the petri dish, it was noticed that some gases were getting deposited after heating above the 150 °C. In order to the check the temperature at which thermal degradation occurred, we have analyzed dust cap and paint samples. Figure 4 shows the weight loss graph of bulb shield painted sample. It can be seen form the figure that bulb shielded paint sample shows two step thermal degradation. The very first step thermal degradation started at around 80 °C and ended at 120 °C with weight loss nearly 9 %. TGA was carried out at isothermal condition at 180 °C for 3 h. It can be seen from the results that some low molecular weight compounds got released in the given temperature range (80-120 °C) and got deposited onto the inside surface of glass headlamp. This deposited VOC results in the reduction in transparency due to the fading mechanism. The visibility of the glass headlamp can reduce if deposition of any volatile organic compound take place onto the transparent surfaces. Headlamp is closed assembly and evaporation of any volatile compounds may deposits onto the inside of the outer lens. Figure 5 displays the reflector paint sample. It can be seen form the graph that 0.085 % weight loss observed in the isothermal conditions which is negligible in the tested temperature range. This reflector paint was also heated up to 180°C for 3 h at isothermal conditions. This concludes that volatile organic compounds got released from bulb shield paint and deposited onto the inside surface of the outer lens. This deposition results in the glass fading and reduction in the transparency of the headlamp outer lens.

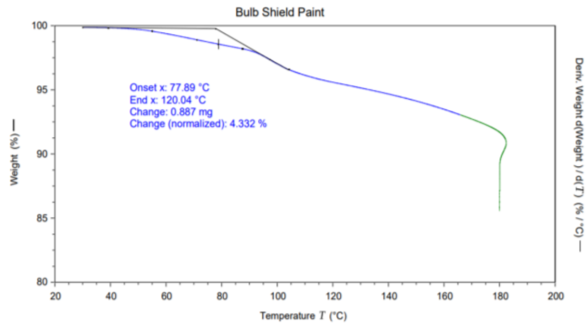

Figure 4: TGA thermograph of bulb shield paint sample

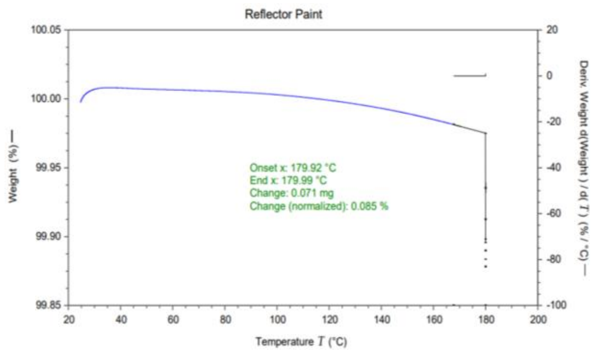

Figure 5: TGA thermograph of reflector paint sample

3.3 Differential Scanning Calorimetry (DSC)

Differential scanning calorimeter was employed to evaluate the thermal properties of the bulb shield paint material. Polymeric coated paint resin generally comes in the thermoset category which upon curing mechanism got crosslinked network and does not change its size and shape. From the TGA and optical results it confirms that some of lower molecular weight compound got evaporated and deposited onto the inside surface of outer lens. In the DSC analysis we have observed that no exothermic and endothermic peaks were present which signifies that no melting and crystallization were observed during the heating and cooling cycle. During the first heating cycle the slight transition in the heat flow curve was observed at 58 °C, 98 °C and 113 °C temperature. This can be attributed to the different paint layers of the coated materials. In the second heating cycle (red line curve), no transitions were observed around 58 °C, 98 °C and 113 °C temperature which clarifies that volatile compounds got released during the first heating cycle only. This confirms that volatile got deposited onto the inside layer of the headlamp outer lens and resulted in the glass fading issue.

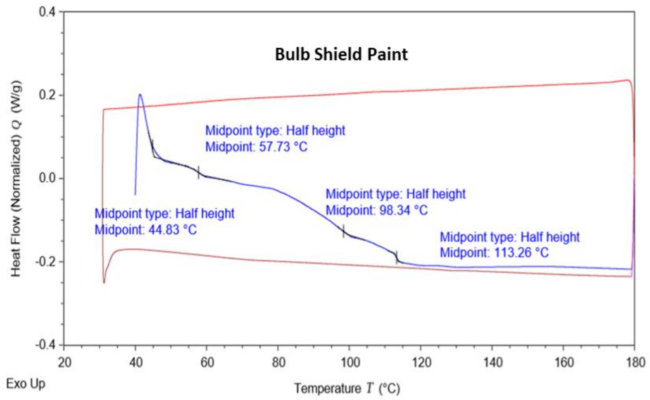

Figure 6: DSC graph of bulb shield paint material

3.4 Petri dish Thermal Box Test

Figure 7 shows the petri dishes before and after the thermal box test. Two petri dishes were used for the analysis. Bulb shield paint sample was scratched and put into the first petri dish. The second petri dish was used to cover the first petri dish as shown in Figure 7 (A). These two-petri dishes were kept in the heating box and the box temperature was raised to 180 °C and kept it for 4 h and this is shown as Figure 7 (B). During the heating cycle, it can be seen that some of the lower molecular weight compounds got deposited onto the inside surface of the second petri dish. This id due to the liberation and evaporation of the volatile organic compound (VOC). It is confirmed form the petri dish thermal box test that in temperature range of 30-180 °C, some of the VOC got released and as the system is enclosed, it got deposited onto the inside layer of the petri dish. Coating paint consist of the number of additives like fillers, antifoaming agents, biocides, wetting agents, extenders. Impurity of these additives may result in the release of lower molecular weight substances. In the Figure 7 (C), it can be seen that after cooling also deposition and black spots were observed onto the inside layer of the second petri dish. This test resulted that fading of the glass surface is caused by the deposition of the volatile organic compound. This glass fading also resulted in the reduction in the headlamp visibility.

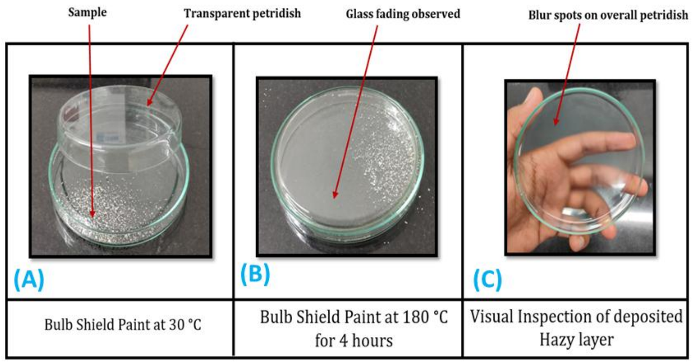

Figure 7: Petri dish thermal box test of bulb shield paint

3.5 Scanning Electron Microscopy (SEM)

The received two-wheeler headlamp assembly part were difficult to place in the SEM assembly. For this attempt, we have carried out the heated petri dish test. The bulb shield paint sample were scratched and put into the petri dish. The petri dish was covered by the second petri dish and heated at 180 °C for 4 h. The volatile organic compounds got deposited onto covered petri dish material and cut into the small pieces for the SEM characterization. **Figure 8 and 9** represents the petri dish small pieces placed for the characterization and deposited micrographs of the released gases. It can be seen from **Figure 8** that volatile compounds onto the petri dish sample have been placed on the SEM sample holder. Figure 9 (A and B) shows that samples at different magnification and can be easily seen that particles after releasing got deposited onto the petri dish surface. The same observation was observed in the headlamp assembly. Figure 9 (A) shows the small black dots of the deposited volatile compound whereas at higher magnification it can be seen that (Figure 9B) glass surface got completely covered with the gas surface.

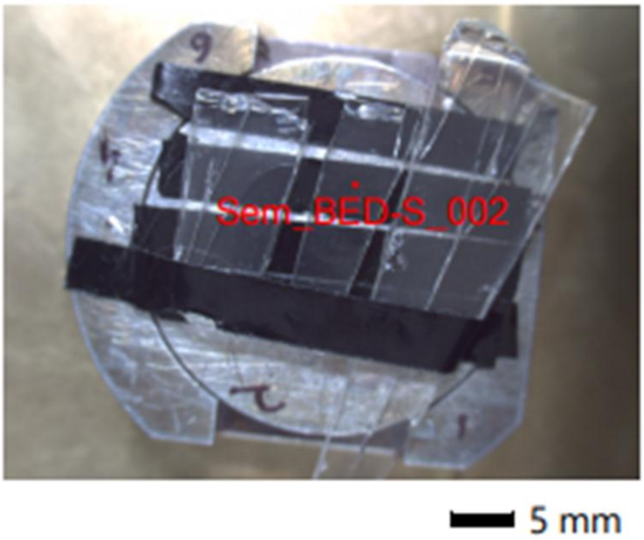

Figure 8: Petri dish pieces after heating at 180 ℃ for 4 h

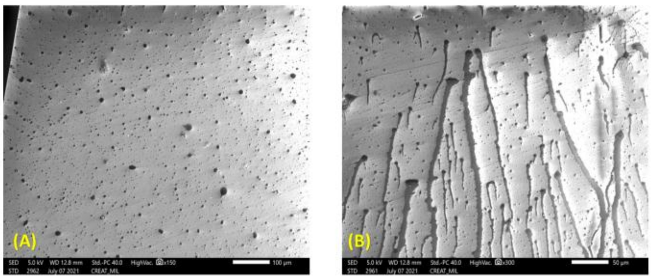

Figure 9: SEM micrographs of faded petri dish sample.

3.6 Glass Fading Remedies and Discussions

Headlamp is one of the most fabricated products of the Minda Industries. Earlier fabricated products were failed to qualify basic standards of the headlamp visibility due to the thermal decomposition of volatile organic components. This liberated VOCs were then deposited onto the inside layer of the outer lens and caused the glass fading issue. In order to resolve this issue, we as a research and development team, have detached all the parts from the headlamp assembly and tested for the thermal, structural and morphological analysis. During the thermal characterization of bulb shield paint, we have identified that there are several lower temperature volatile organic components are present in the system which causing the glass fading issue. Coating paint should have prepared with purified additives to avoid the release of low molecular weight compound. Coating resin and hardener system should have prepared in optimized ratio to avoid partial crosslinking of resin. After rectifying the issue, we have asked the paint vendor to change the formulation of the paint material with virgin grades of the filler and additives material. Also, aske them check the impurities present in the additives compound. We have also set and followed some primary characterization steps for every new consignment to avoid any further complications in the headlamp visibility.

4. Conclusion:

In this study, different characterization methods are used to find out root cause for the glass fading issue observed on to the glass headlamp outer lens. For the initial screening, we have used the optical microscopy images to confirm the deposition of volatile gases. Also, for the fine-tuning and final confirmation, we have used thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC) analysis. TGA analysis conformed that there was weight loss in the temperature range of 80-120 °C. This low temperature decomposition attributed to the release of the volatile organic compounds. In the DSC curve also, irregular heat flow curve was noticed around 58 °C, 98 °C and 113 °C temperature range. This irregular heat flow pattern was absent in the second heating cycle which confirms the release of the volatile substances takes place during the first heating cycle only. The optical images of the deposited layer of gases released during the petri dish test of painted bulb shield confirms there is a release of some volatiles, which is being deposited onto the internal surface of headlight lens. The same thing we have observed from the TGA analysis. In the petri dish test at 180 °C for 4 h, we have noticed that some of the particles present in the paint sample got evaporated and deposited onto the petri dish sample. TGA and DSC analysis concluded that weight loss and irregularities in the heat flow was observed nearly temperature range of 80-120 °C. SEM analysis concluded that there were some morphological changes in the paint sample along with the non-uniformity in the paint layer.

ACKNOWLEDGEMENT

The authors would like to thank Minda-Rinder plant for cooperation throughout the characterization and analysis process. The authors also thankful to the management team of Minda Industries Limited for the motivation.

REFERENCES

[1] J. A. Sanguesa, V. Torres-Sanz, P. Garrido, F. J. Martinez, and J. M. Marquez-Barja, “A review on electric vehicles: Technologies and challenges,” Smart Cities, vol. 4(1), Mar. 2021, pp. 372-404, doi:10.3390/smartcities.4010022.

[2] Y. Miao, P. Hynan, A. Von Jouanne, and A. Yokochi, "Current Li-ion battery technologies in electric vehicles and opportunities for advancements," Energies, vol. 12(6) Mar.2019, pp.1074, https://doi.org/10.3390/en12061074

[3] D. Heitbrink, C. Schwarz, and W. Wang, “Simulation of Automotive Headlights for Human Factors Research,” IMAGE, June.2017.

[4] Muttart, Jeffrey, Wade D. Bartlett, Chris D. Kauderer, Grant L. Johnston, Matthew RE Romoser, Jan Unarski, and Daniel Barshinger, "Determining when an object enters the headlight beam pattern of a vehicle, " SAE, April. 2013, pp. 01-0787, http://dx.doi.org/10.4271/2013-01-0787.

[5] C. Macías, O. Meza, and E. Pérez, "Relaxation of residual stresses in plastic cover lenses with applications in the injection molding process," Engineering Failure Analysis, vol. 57, Nov. 2015, pp.490-498, https://doi.org/10.1016/j.engfailanal.2015.07.026

[6] C.D. May, and R.J.Watling, "The development of analytical and interpretational protocols to facilitate the provenance establishment of polycarbonate headlamp lens material,". Journal of Forensic Sciences, vol. 56, Jan. 2011, pp.S47-S57, https://doi.org/10.1111/j.1556-4029.2010.01590.

[7]B. T. Anthony, "Lexan polycarbonate for automotive forward lighting," Materials & Design, vol. 6(6),Dec 1985, pp.293-302, https://doi.org/10.1016/0261-3069(85)90011-1

[8] C. Tuchinda, S. Srivannaboon, and H.W Lim, "Photoprotection by window glass, automobile glass, and sunglasses," Journal of the American Academy of Dermatology, vol. 54(5), May.2006, pp.845-854, https://doi.org/10.1016/j.jaad.2005.11.1082

[9] M.E. Nichols, and C.A. Peters, "The effect of weathering on the fracture energy of hardcoats over polycarbonate," Polymer degradation and stability, vol. 75(3), Jan 2002, pp.439-446, https://doi.org/10.1016/S0141-3910(01)00244-0

[10] C. Seubert, K. Nietering, M. Nichols, R. Wykoff, and S. Bollin, "An overview of the scratch resistance of automotive coatings: exterior clearcoats and polycarbonate hardcoats," Coatings, vol.2 (4), Nov. 2012, pp.221-234, https://doi.org/10.3390/coatings2040221

[11] Y. M. Yusoff, M.K. Omar, M. D. K. Zaman, and S. Samad, "Do all elements of green intellectual capital contribute toward business sustainability? Evidence from the Malaysian context using the Partial Least Squares method," Journal of Cleaner Production, vol. 234, Oct. 2019, pp.626-637.

[12] D. Kyriacos, "Polycarbonates," In Brydson's Plastics Materials, Jan.2017, pp. 457-485. Butterworth-Heinemann, https://doi.org/10.1016/j.jclepro.2019.06.153

[13] M.D. Pustode, C.S., Singh, R. Verma, T. Kochi, H. Barge, S. Gouda, and A. Dutta, "Root Cause Analysis and Mitigation of White Patch Formation in Automotive Headlamp," Journal of Failure Analysis and Prevention, vol. 21(2), Apr.2021, pp.387-397, https://doi.org/10.1007/s11668-021-01120-y

[14] P. Sarkarand and A.K. Bhowmick, "Sustainable rubbers and rubber additives," Journal of Applied Polymer Science, vol.135 (24), June.2018, p.45701, https://doi.org/10.1002/app.45701

[15] M. J. Samide and G. D. Smith, "Analysis and quantitation of volatile organic compounds emitted from plastics used in museum construction by evolved gas analysis–gas chromatography–mass spectrometry, "Journal of Chromatography A, vol.1426, Dec. 2015 pp.201-208, https://doi.org/10.1016/j.chroma.2015.11.066

[16] M. Barletta, M. Puopolo, G. Rubino, V. Tagliaferri, and S. Vesco, "Hard transparent coatings on thermoplastic polycarbonate," Progress in Organic Coatings, vol.90, Jan.2016, pp.178-186, https://doi.org/10.1016/j.porgcoat.2015.10.014

[17] H. Yahyaei, M. Mohseni, and S. Bastani, "Using Taguchi experimental design to reveal the impact of parameters affecting the abrasion resistance of sol–gel based UV curable nanocomposite films on polycarbonate, "Journal of sol-gel science and technology, vol.59(1), July.2011, pp.95-105, https://doi.org/10.1007/s10971-011-2466-z

[18] M.D. Pustode, C.S., Singh, R. Verma, T. Kochi, H. Barge, S. Gouda, and A. Dutta, "Root Cause Analysis and Mitigation of White Patch Formation in Automotive Headlamp," Journal of Failure Analysis and Prevention, vol. 21(2), Apr.2021, pp.387-397

BIOGRAPHIES

Mr. Ikhlas Chandkoti is senior executive in UNO Minda Industries. He is a B.Tech. in Polymer Engineering and working on the several projects regarding thermal management in electric vehicles.

Dr. Amol Naikwadi is research lead in UNO Minda Industries. He has completed his Ph.D. Tech. in Polymer Engineering from Institute of Chemical Technology Mumbai. His expertise is polymer synthesis, polymer thermal management, polymer composites, energy storage.

Dr. Manoj Mali is principle scientist in UNO Minda Industries. He has completed his Ph.D. Tech. in Polymer Engineering from Institute of Chemical Technology Mumbai. His expertise is polymer blends and alloys, failure analysis and prevention, polymer thermal management, and composites.

Mr. Srikanth T.S. is general manager in UNO Minda Industries. He is an Electronics Engineer. Have extensively worked on software development, test, deployment and support. Proven skills span across Delivery management, evaluating existing processes for improving effectiveness and efficiency, Outsourcing solutions & Contract Management.