Review paper on automotive headlight reflector coatings and improve its corrosive resistance

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ABSTRACT:

Night time driving is made comfortable with the advent of automotive headlights and in special the adaptive headlight system. For all headlight system to perform well, the reflector design, shape and the coatings involved in it plays a major role. This paper elucidates the optimum methods of manufacturing a reflector case effectively, thus maintaining the warpage and shrinkage control of the same, various coatings applied using various coating methods and thus suggesting the optimum coating material and the procedure. In addition, providing an end coating on the coated material over the reflector body to enhance its corrosive resistance nature.

Keywords:

Reflectors, Micro Arc Oxidation(MAO), external Gas Assisted Injection Moulding(eGAIM), Polymethyl methacrylate(PMMA), Scanning Electron Microscopy(SEM).

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1. INTRODUCTION:

The reflectors of an automotive headlight helps in illuminating the road ahead by reflecting all the lights incident on it to the roadway, from the light source. Thus, the reflector plays a major role in assisting the night time driving. This gives us the view that the shape and the reflecting capacity of the reflectors decides the efficiency of the same. The reflecting ability is achieved by means of coating the inner part of the reflector case with some thin and fine layer of reflecting materials such as aluminium, alumina, etc.

The above mentioned characteristics (viz., part stability and the reflectivity) of the reflectors are studied form various papers, thus collecting the basic information of the optimum method of production of the same, various types of coatings that can be given to it, along with the methods of coating and also the provision of an additional coating to enhance the corrosive resistance of the reflector. This paper elucidates the collected information in a way as to arrive at the best among the available methodologies.

2.1 REFLECTOR MAKING:

In general, the reflector case are made of either aluminium or thermosetting plastics, and are usually the widely used materials for their make worldwide. The conventional method of Injection moulding is the process used to make the reflectors in a cost effective way. But, it is found that the reflectors made by this method suffers part shrinkage and warpage defects, leading to the formation of unevenly thickened reflector body.

This is due to the temperature and pressure distribution during the moulding process, the internal stresses produces warpage depending on the relative thickness of the material. **R.Sanchez et al** suggested that cooling time was the major parameter to reduce warpage and the difference in cooling temperature lead to 70% of the maximum values. So it is important to take into consideration the cooling parameters while making the reflectors by Injection moulding process to keep in control the warpage and shrinkage [5]. An optimum mould temperature was suggested by Shih-Chih Nian to reduce and keep the warpage of the part under control. They conducted experiments by producing parts at different temperatures like 50,60,70ºC and the results revealed that, at 50ºC the minimal warpage and flatness of about 0.65 mm was achieved [6].

Such conventional methodologies as maintaining the mould temperature at the desired level, the cooling conditions and performing annealing as a secondary process could be used to reduce the amount of such defects, but the quality will not be of that much as intended. So, external Gas Assisted Injection Moulding (eGAIM) method with high holding pressure can be used in the make of reflectors [1].

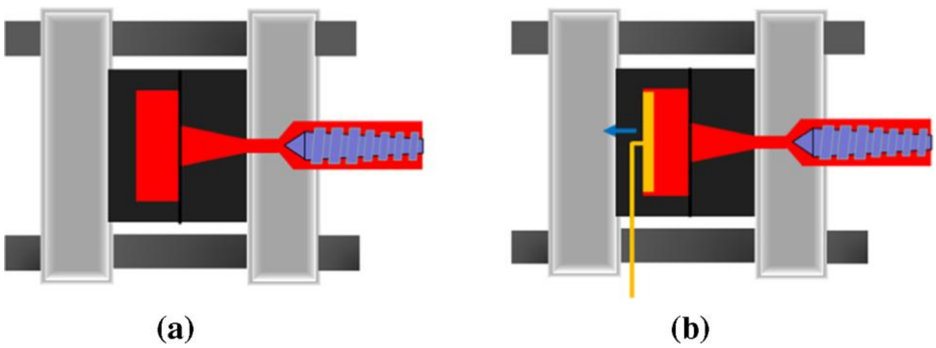

Fig 1: external Gas Assisted Injection Moulding(eGAIM)

Lim li Xin et al, elucidated that external Gas Assisted Injection Moulding has the capability of good compatibility, and offers less warpage and shrinkage, reduced sink and flexible design purpose. They proved that reducing the melt and mould temperatures, warpage can be controlled to a greater extent. They suggested the following parameters for the optimum eGAIM process [7].

Table 1. Optimum eGAIM process parameters

Factor	Parameter	Low level	High level
A	Melt injection time	1 s	3 s
B	Gas delay time	1 s	3 s
C	Melt temperature	220 °C	240 °C
D	Mold temperature	50 °C	70 °C
E	Gas injection pressure	5 MPa	7 MPa

One defect in moulded parts is the ghost marks, that occur as a result of uneven part shrinkage. These refract light in a way that these can be differentiated from the other part region. **Heng yi su et al** represented that at higher injection speed and higher holding pressures with inert gases reduced the colour variations (i.e. ghost marks) [2].

Adaptive headlights provide great support in night time driving, making the road get illuminated along the steering direction. This is proved by the test conducted by **Ian.J Reagen et al,** by placing targets to detect on road sides, and used three different headlamp sets, Adaptive with HID, fixed HID, and with halogen headlights. Results showed that the Adaptive with HID headlight, detected maximum number of targets comparatively, thus suiting the need by assisting the drivers [3]. So, the above mentioned technique of making the headlight reflectors could be implemented in the making of these type oh adaptive systems, such that the comfort achieved could be comparatively high. Recent development of LED matrix headlights in adaptive systems helps in avoiding glares for the upcoming or approaching vehicles, by turning certain cells of matrix to off condition on sensing the vehicles [4].

2.2 Coatings for reflectors:

The materials used for the making of headlamp reflectors are mostly Aluminium and its alloys, Thermosetting Plastics like Polymethyl methacrylate(PMMA), Chrome steel etc., These are then coated with reflective layers made of mostly aluminium, aluminium, tungsten, magnesium, phosphorous, Nickel and such materials possessing reflective, stable and wear resistive properties.

Another useful material used for coating is Nickel(Ni).This along with phosphorous is used to coat aluminium alloys, because of their mechanical and chemical properties such as high wear and corrosive resistance. However, Al being less dense is a problem for usage. So, Ni-P is coated over Al alloy by co deposition by cathodic plasma electrolysis. The test was conducted by **Yedong he et al,** to check the feasibility of the idea. The test showed that, in the beginning stage of the experiment, the amount of phosphor deposition decreased with increased start voltage. As the test continued, and the coating got stabilized the voltage reduced and the phosphor got deposited in an increasing manner. This co deposition enhanced the wear and corrosive resistance property of the alloy [9].

One of the alloy used for the making of the reflector is Al-2124. **Feng cheng et al** conducted experiments on this alloy by coating it with Micro Arc Oxidation method, which in turn is one of the methods employed for coating the reflectors. Experimental tests such as Scanning Electron Microscopy(SEM) showed that the MAO coated Al alloys showed higher resistance to cavitation erosion, which is the one that limits Al from use in high temperature and liquid zone regions. They showed results like the Mean Depth Erosion(MDE) of Al alloys coated with MAO method remained constant and is almost zero(0) after 30h of test period, which makes sure that the incubation period of the Al alloy is increased to a greater extent than those which are not coated [8].

Aluminium is the widely used coating element for the reflectors. A test was conducted on the layer thickness of Al coatings on PET by **Daria.A punchuk et al,** in order to find the thickness properties of the same. Al was coated on the target by thermal sputtering method, and it is known that the thickness of the coating is directly proportional to the metal deposition time. Experimental results showed that thin Al coatings exhibited greater yield strength and yield stress than that of thick coatings, which in turn is due to the fact that as metal deposition of Al increases, the grain size increases forming islands of material on the target. Thin Al layer has lesser grain size and thus the greater stability. Alexander L. Volenskii et al determined the structure and mechanical properties of thin aluminium coatings by measuring its yield stress, strength ,fracture of thin coatings that were developed. The results revealed that decrease in thickness of coatings will increase the yield stress, strength, fracture and the results also says that aluminium coating should be greater than 5-10 nm and if the coating is less than that the specified range, it will be amorphous in state [10]. These find their use in applications other than reflector coatings like glass coatings, optical reflectors etc.

Some of the techniques adopted for coating on the reflector case are Micro Arc Oxidation(MAO), DC and RF Magnetron Sputtering, Cathodic Plasma Electrolysis(CPE), Electron beam Physical Vapour Deposition(EPVD). Referring various papers, the advantages of the various methods used are studied.

The vapours of tetramethyldisiloxane and oxygen is used to deposit coatings on PMMA. These coatings have effect on physical and chemical properties of coatings deposited on the surface. Varying oxygen content while depositing will have high level of grading. During the process, we have varied the flow rate of oxygen to test the refractive index, stress levels and adhesion to PMMA. Abrasion and durability was also determined. For greater coating performance, increase of oxygen content will have a good effect [11]. So, while coating of reflectors in micro arc oxidation increasing the oxygen content will have greater effect in durability and reflectiveness.

While, fabricating Al-Cu-Fe coatings using Electron-Beam Physical Vapour Deposition(EBPVD) , structure of coatings contains defects, like cracks while cooling at room temperature. These, defects are due to the stresses developed while cooling at room temperature, to overcome this defects we are considering the thermal expansion coefficient and fracture toughness. During thermal expansion, the coatings change its volume and area in response to change in temperature. Fracture toughness is the indication of amount of stress required to propagate a pre-existing flaw. These two values are used to determine the critical thickness. The channel cracking can be avoided by fabricating thinner coatings than the critical thickness value. In the process of headlight coatings we can consider this critical thickness values to avoid channel cracking [12].

Aluminium coatings barely when coated possess poor wear resistance at atmospheric conditions and high temperatures. To overcome this effect, Aluminium oxide layers are being used for this application. **E.Arslan et al,** analysed the wear resistance of the Aluminium Oxide layers at different temperatures using SEM and XRD techniques and found that the lowest wear rate was obtained at 200ºC, which is quite good as in the case of headlight case conditions where the coatings are employed [13].

Ji Zou et al, conducted tesing usig SEM on three different Micro Arc Oxidation coating methods, namely MAO, NMAO and High temperature MAO to determine the cohesive behaviour and corrosion resistance of the three and arrive at the best coating methodology. Among these, the Normal Micro Arc Oxidation(NMAO) method showed higher adhesion with the target and possessed high corrosive resistance. This method could be implemented in the coating process of the reflectors in our case [14].

The bond strength of the coatings on the reflector case should be considerably appreciable in order for it to be stable and wear resistant. For this a method that involves cold spraying of Aluminium and Aluminium di oxide is used, where in the particles of the constituent that are of 1-50 micrometers in diameters are accelerated to strike the target particle and they deform plastic deformation at the surface such that they impend on to the layer thus increasing the bond strength. Coating thickness of about 250-3000 micrometers Coated were tested by SEM and wear resistant testing under neutral salt spray solution, gave results giving bond strength upto 61MPa which is good for the coating not to get eroded away [15].

For corrosive resistance to be high, reduced oxidation is necessary. This was achieved by adding some amount of Tin and Silicon along with the Aluminium material to be deposited over the target. When this was coated over the target, the testing results gave high hardness in the range of (>40GPa), and high oxidation resistant upto elevated temperature upto 800◦C. It also gave results like it prevents the oxygen to get diffused into along the grain boundaries. This considerably shows preventing corrosion effectively [16].

Chen Liu et al, conducted experiments on Plasma Electrolyte Oxidation method of coating of Aluminium on the target material using two different electrolytes one being the common acetic solution of KOH for PEO and the other being mullite solution. These are then tested by electrochemical impedence microscopy after long term immersion in 3.5% wtNaCl solution. The results showed that some coatings were detached from the surface treated by electrolyte 1 shows more stability than the mullite solution treated coating. It was capable of withstanding the testing environment more than the other comparatively [17].

Chang-Sheng Liang et al, conducted experiments by coating aluminium along with environment friendly molybdate and tested by SEM, X-ray Photoelectric spectroscopy(XPS), and found that the corrosion resistance of these coatings were much more higher than those with bare aluminium coatings. They added that this method is also suitable for continuous processing [18].

Yung-Chin Yang elucidated the properties of aluminium nitride coatings coated by impulse magnetron sputtering method. These have good chemical and physical properties and the hardness was found to be increasing with the lowering of duty cycle and increasing peak power. Greater hardness was achieved around 26.5 to 28 GPa. With increasing frequency, the adhesion property of the coating was also found to be increasing [19].

Fatma Ahnia et al conducted experiments on Aluminium coatings coated by electric arc spray process by subjecting it to simulated marine environment. The samples have been heat treated between 200 and 600ºC, and were characterized by SEM, XRD and EDS processes. These tests revealed that the protection of the target is better when the coatings are between 200 and 500ºC [20].

M.Rostami et al conducted experiments on aluminium pigments by coating them with cerium oxides/hydroxides, in order to test the enhancement in its corrosive resistance. The corrosion resistance of the pigment was evaluated by conventional hydrogen measurement in acidic solutions and electrochemical impedence spectroscopy in 3.5% NaCl solution. Results showed that the pigments treated with cerium showed greater improvement in its corrosive resistance, after being immersed in cerium rich solutions [21].

Ying Gao et al, conducted experiments to test the corrosion process of ceramic coatings on aluminium alloy by silicate electrolyte system and the surface morphology nd phase changes were analysed by SEM and XRD techniques. The results revealed that 5 g/L of Na2WO4, when coated at lower arching voltage provide high corrosion resistance. These coatings have 1.6 times corrosive resistance than normal ceramic coatings. So, this process of coating can be used to coat the reflector to obtain good resistance to corrosion [22].

As an optimum method for achieving greater withstandability and corrosive resistance, can be achieved by using four different types of layers, the first one being the application of a lacquered layer, the second one being a protective layer of mostly Hexadimethylsilane, the third one being the key metal of coating, and finally again the protective layer of Hexadimethylsilane. Experimental results showed that these method of coating gave greater stability than those without a protective layer on top [23].

3. CONCLUSION

This study involved the study of reflectors and consisted of broadly three divisions. One being the optimum method of reflector making using external Gas Assisted Injection Moulding (eGAIM) process, the second being the various types of materials coated on the reflectors body, and finally the optimum method that can be used for the coating of the materials on to the reflector body. Based on the study involved, we arrive at the following conclusions,

1. Conventional Injection Moulding technique employed for the making of the reflector body, yielding parts that suffer defects such as shrinkage, warpage and ghost- marks. These are backed by some conventional techniques like optimizing the cooling system, mould conditions and performing annealing as a secondary process, but does not yield the intended quality. So, external Gas Assisted Injection Moulding(eGAIM) can be opted for the make of the reflectors, which involves a two stage holding pressures instead of a single high pressure holding. This is found effective on comparing the yielded components.
2. In addition to the technique employed, reduction in melt and mold temperatures, warpage can be effectively controlled. The other being, increasing the injection speed, the ghost marks can be reduced effectively. Thus, eGAIM is a optimum method of manufacturing the reflector of intended geometry.

3. Aluminium is the widely used coating material for reflectors. This when coated barely possesses poor wear resistance. So, optimum solution may be the use of Aluminium oxide layer coating which has comparatively high wear resistance. Another material is the tetra methyl di siloxane, used for coating plastic reflectors. These should be coated on to them with increased oxygen supply, in order to arrive at a abrasive resistive, durable, more reflecting and highly adhesive coating.
4. Based on the study, Micro Arc Oxidation(MAO) is the best coating method which is flexible enough to the type of the target on to which the coatings are being coated. This method is applicable for coating both the Al alloy and Plastic reflectors, and is found to give coatings of high bond strength, such that it is not eroded away, and alos improves cavitation erosion resistance.
5. To arrive at a conclusion for the property of the coating, the thickness of the coatings should be thin and not thick, as thin Al coatings has high yield strength and yield stress and this thickness should be less than the critical thickness value of the coating. This ensures the prevention of channel cracking on the coatings coated.
6. In order to improve the corrosive resistance of the coatings, Tin and Silicon can be added to the aluminium being coated, which gives high hardness value of the coatings(>40GPa) and increased oxidation resistance(upto 800ºC). This proves to increase the corrosion resistance effectively. Another method is the addition of Molybdate to the Aluminium being coated, which also gave similar results. In addition, treating the coatings with cerium also showed increased corrosive resistance..
7. For the coating to be higky withstanding and corrosive resistive in nature, a process of four layer coating can be employed. The first one being a lacquer coating, the second being the hexa methyl disilane protective coating, the third being the main material coating and finally again the hexa mthyl disilane coating. This proves to be a effective procedure for coating on reflectors.

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