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To Explore the Effect of Injection Molding Processing Parameters on Crazing in Acrylic Polymers

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Summary: Plastic manufacturing industry is the fastest growing industry as the demand for plastic products is exponentially growing worldwide. Poly (methyl methacrylate) (PMMA), also known as acrylic glass, is a transparent and rigid thermoplastic. PMMA is highly resistant to UV light. Weathering has an excellent light transmission and unlimited coloring options compared to other transparent plastic and has been used in wide applications such as architecture, automotive and transportation, lighting (LED lights), medical and healthcare, and furniture. Injection molding is the widely used plastic manufacturing process to produce plastic products for various applications. The quality of the plastic products depends on the injection molding parameters, viz. melting temperature, injection speed, and pressure, holding and cooling time, and holding pressure. Therefore, it is important to control injection molding parameters to reduce injection molding defects or parts. Hence, the main objective of this research is to optimize the injection molding parameters, including the amount of mold releasing agent, to avoid the crazing marks in PMMA which is a long-standing problem in the production of PMMA products or parts such as motorbike headlight lenses. Three different holding pressures (65, 75, and 85 kg/cm^2) were varied against three different injection pressures (70, 80, and 90 kg/cm^2). The injection speed (60 %), cooling time (4 s), and barrel zones temperature (185-205: 185-205: 190-210: 195-215) were kept constant not to disturb the production cycle, a constraint from the production industry. The minimum criteria required for the motorbike headlight lens selection was based on the LUX intensity test, density, and crazing demanded by the Japanese standard throughout this research. The optimized injection molding parameters and amount of mold releasing agent (Nabakem mold release R2) were 70 kg/cm^2 (injection pressure), 65 kg/cm^2 (holding pressure), and 1.18 g, respectively. The motorbike headlight lens produced with optimized injection molding parameters showed no crazing. In addition to the desired LUX intensity, density, and no crazing criteria, the motorbike headlight lens also showed improved impact properties and no substantial changes in mechanical properties when compared to virgin PMMA or literature. Hence, it is concluded that the optimized injection molding parameters (thermo-mechanical history) did not much affect the molecular weight and morphology of the PMMA.

Keywords: Acrylic polymers; Headlight lens; Injection molding; LUX intensity test; Poly (methyl methacrylate).

Introduction

Since the last decay, every sector is getting replaced with plastic from metal and glass. Metals are being replaced to lighten the weight, while glass has brittle characteristics. Transparent plastics PC, PMMA is used instead of glass in lamp lens. However, despite getting so many benefits from plastics, like excellent light transmission, due to high resistance to UV light and weathering, and unlimited coloring options in comparison to other transparent plastic, such as polycarbonate and polystyrene, PMMA has been used in wide applications such as architecture, automotive and transportation, lighting (LED lights), medical and healthcare and furniture. However, poor impact, wear and abrasion resistance, limited heat and chemical resistance (notably chlorinated hydrocarbons, aromatics, esters, and ketones), cracking, and crazing under load are the main hurdles widespread applications of PMMA. To overwhelmed the shortcomings, many routes such as incorporating inorganic particles, dispersed rubber phase, and plasticizers are reported in the literature [1, 2].

To illustrate different processing parameters on the behavior of crazing properties and tip shape. Crazing is a reversible defect that appears on the lens not immediately after production but after a while. That means crazing is a time-dependent defect. In factories, it is unable to spot the crazing during production, and as a result, defective pieces will be on the customer's table. Sorting is not the permanent countermeasure for crazing at all [3, 4].

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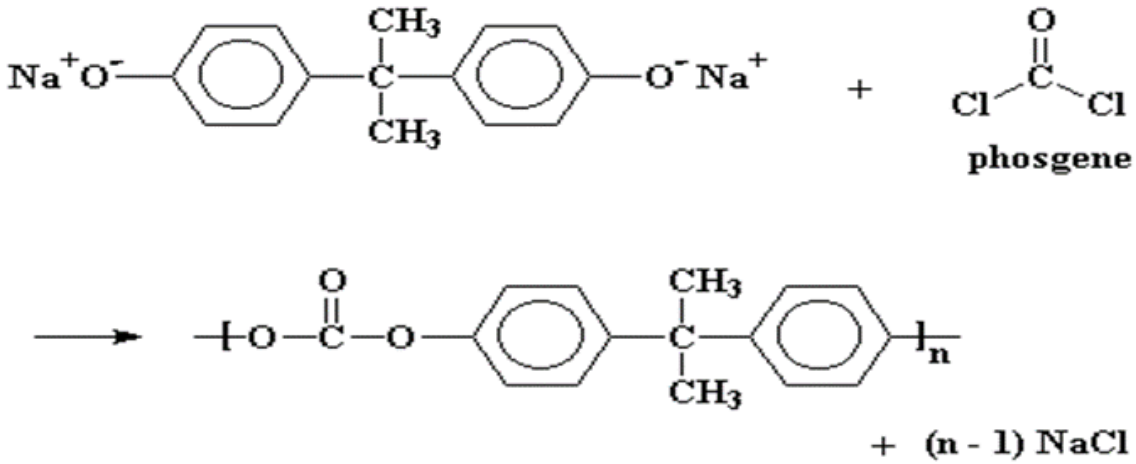


Fig. 1: Composition and structure of polycarbonate.

The researchers have developed a model to correlate the crazing to the molecular weight of polymers, entanglement density, and the force required to break the carbon-to-carbon bond on the main backbone of polymers. Stress-based and strain-based criteria have also been developed to understand craze development and growth. Researchers have used injection molding processes to produce PMMA samples and overcome the limitations of pristine PMMA. From the above literature review, the authors, as per their knowledge, understand that no single study has thoroughly investigated the industrially preferred melt injection molding process, parameters on the crazing in PMMA [5, 6].

Long sequences of one or more species of atoms or groups of atoms linked to each other by primary bonds are called Polymers. Polymers form a very important class of materials without which life seems very difficult. They are all around us in everyday use; in rubber, in plastic, in resins, and adhesives and adhesives tapes. Polymers have helped society in several ways. They are preferred over other materials due to their properties in the same way plastic has become one of the most frequently used materials in the automatic sector. Material is transparent if it lets light rays through without scattering or deflection of light; they do not show any shadow. Similarly, transparent polymers have sufficient space between their lattices to pass the light. Mostly amorphous materials are transparent. In vehicles, so mostly use polycarbonate and polymethyl methacrylate for the lamp's lens.

Polycarbonate (PC) is a high-performance amorphous, tough, and transparent thermoplastic polymer with functional groups (-O-(C=O)-O-) linked together, as shown in Fig 1. The full structure of PC and composition reaction is described in Fig 1. Polycarbonate resin is melted and pushed into the mold with high pressure to give it the desired shape. The automotive sector is a fast-growing sector mainly used in injection molding for polycarbonate parts. Usually, PC proceeds at high temperatures; it is a highly viscous material. Moreover, due to its poor flowing nature, its wall thickness should not be too thin. Considering it as transparent and lightweight, it makes an eye-catching design and promotes vehicle efficiency by decreasing weight without affecting durability and enhancing the aerodynamics of a vehicle [7, 8].

PMMA, also called acrylic or acrylic glass, is a transparent and rigid thermoplastic material widely used as a bulletproof replacement for glass. With functional groups (-H_2C=CH-C(=O)-) linked together as shown in Fig 2. PMMA is 100 % recyclable but non-biodegradable material. Recycled acrylic is used as sheets in windows, doors, and the medical sector. Pre drying of up to 8 hours at 70~100 degrees centigrade is necessary for processing polymethyl methacrylate. Due to poor flow properties, High injection pressures are needed with the slow injection to achieve correct flow. In vehicles, PMMA is used in car windows and motorcycle windshields. Also, use in lamp's lens and cover. Due to pleasant soundproofing properties, PMMA unlocks new design opportunities for the car manufacturer [9, 10].

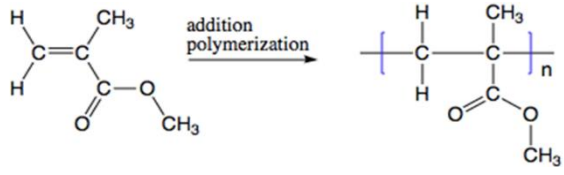


Fig 2: Structure of polymethyl methacrylate (PMMA).

Polymethyl methacrylate has better starch resistance than polycarbonate. PMMA does because PMMA does not change its transparency to yellow with time, less damaging to tissues when it fractures. That's why it is the better option for optical devices. PMMA can be polished to recover its clarity, while PC cannot. PMMA has miserable chemical resistance than PC. PMMA has good color stability as well as good esthetics. Relatively inexpensive than other transparent polymers. Light in weight and easy molding is also two of its important benefits. PMMA has poor durability, limited heat resistance, and has prone to crazing.

Crazing is the phenomenon that generates a network of fine cracks on the surface of a material. Crazing is a micro void that grows similar to crack normal to the main force. Acrylic cracking results from either thermal or mechanical stresses conveyed during production, transport, manufacture, or use. Fine crack network on the face of the material; it can be visible within a few days of production but can occur at any time. It is reversible, can't be felt at the surface, and continue to sustain the load. While cracking is thin sharp pointed edges space [11, 12].

The injection molding process is the most efficient plastics manufacturing method. In comparison to other polymer processing techniques production of a product with low cost and complex geometries are the main advantages of injection molding when compared to other conventional polymer manufacturing processes. On the other hand, short shots, silver streaks, voids, jetting, crazing, weld marks, and floating fibers are some of the problems that need to be overcome during injection molding processes. Crazing is an undesirable micro-void (filamentous speckle) that develops, on the surface or near-surface of a product, normal to the main stress or strain axis due to the mold shrinkage or machining process temperature changes or the action of solvents or chemicals. Crazes can be viewed with a naked eye as they flicker and emit light when viewed at a certain angle. Initiation, craze growth, and craze breakdown are the main steps in crazing; after their formation, craze grows in length and width [13, 14].

The main purpose of this research is to resolve the crazing issue during injection molding by optimizing injection molding parameters and evaluating the defect in detail, moreover to see the effect of chemicals and aging on crazing. Fig. 3 shows the real-time crazing.

The relevant literature has discussed the evaluation of crack and craze growth resistance in transparent polymers in the presence of several surface-active solvents. It quotes, "the craze growth rate of PMMA in ethanol was much faster than that of polycarbonate." Moreover, it also explained the structural effects in amorphous thermoplastic due to environment-induced degradation. It also gives a sneak into the polymers as when they go into the adverse condition of the environment, due to one of the shortcomings of the polymer materials, they lose their inherent mechanical properties. Due to this particular problem, most glassy polymers can show a trend in crazing or cracking on even a very small magnitude of stress. It has also been seen that sometimes the crazing phenomenon does not even require additional applied stress or an adverse environment to appear on the surface of the polymeric material. The molded-in stress only can contribute to the appearance of the crazes when it goes just above its critical value [2, 11].

C.L Walter, in technological Spinoff report, has done the working on PC which includes, the contact of different chemicals, releasing agents and solvents to polycarbonate parts and the study shows that these chemicals can cause crazing on the surface of components formed with polycarbonate. In some cases, polycarbonate was tolerant of exposure, but when aerosol contacted the polycarbonate component, crazing was observed. To determine the absolute effects of these chemicals and solvent's properties of polycarbonate and the factors leading to the formation of crazing on the surface of the parts, molded-in stresses of the component were identified. The study concludes that only some chemicals and solvents will give a notch to crazing or cracking in polycarbonate components if the stress level is higher than the limit. Furthermore, the coolants used for the purpose contain chemicals that facilitate crazing and cracking. So, it was suggested in the research work only to use those highly purified solvents. For cooling purposes, highly purified oils and solvents are compatible with polycarbonates [15, 16].

Environmental stress crazing produces when a polymer component is revealed to the chemical when under stress. Crazing and cracking appear partly due to partial chain disentanglement in the regions of high stress. The solution to internal part cracking is to vary the packing pressure. Tiny hairline cracks of a molded part surface are caused by chain direction and orientation at the face of the plastic part. Always there is some stress on the surface of the plastic sample. Over some time, chemical attacks or sunlight will diminish the strength of the plastic until internal stress makes these cracks. Excessive mold release will interrupt molecular bonding, weakening the part [17, 18].

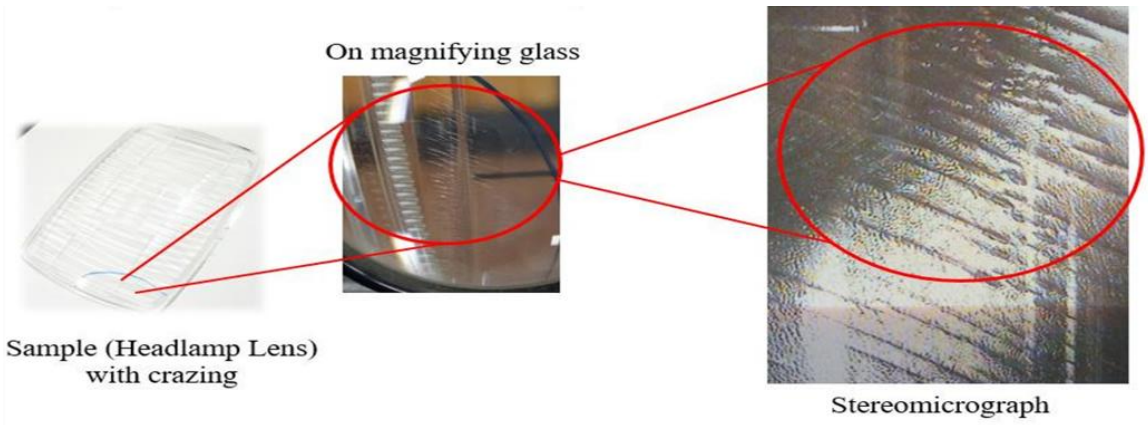


Fig. 3: Real-time crazing.

Robeson has reported the effect of weathering, temperature, humidity and reports the increases in crazing. It has discussed the effect of crazing in biopolymers which suggests that crazing significantly appears when a rubber goes into the glassy/ amorphous state. What happens when the surface contracts and loses its water yields which contribute to cracking and crazing on the finished material. The stress cracking of glassy polymers can be seen when PMMA contacts dimethyl phthalate. During the mechanism, the appearance of cracks, it can be noted that the direction of cracks was perpendicular to the surface of the polymer, which was possibly due to the swelling of glassy polymer in the presence of internal stresses. During the whole mechanism, there were no added stresses applied on the surface of the polymer. Those molded-in stresses were significant enough to cause the crazing. It is due to the penetration of the solvent into the glassy polymer, which tends to produce internal stresses [19, 20].

Shields *et al.* summarized in their research that mold release agent gets absorbed by epoxy resin during the molding cycle. Release agents that are mainly used for molding purposes are silicon-based. The primary function of mold release agents is to remove the polymer component from the mold. The study has shown that while these silicon-based release agents help remove the part from the mold without any damages. But at the same time, some amounts of these release agents are being absorbed by the component, which can probably instigate a change in polymer properties. In actual practice, when a part is separated from the mold with the aid of a mold releasing agent, the molecules of the mold releasing agent go into shear. The molecules of release agents tear apart; some molecules stick to the mold while some go with the surface of the polymer [2, 9].

Pawar, E. crazing is observed more in amorphous and brittle polymers such as PS, PC, and PMMA. It also concluded the Mold release interfered with that bonding and caused crazing to occur on the part's surface. The mold release agent gets into the intermolecular structure of the polymer. It is permissible and weakens intermolecular forces, common for brittle and amorphous polymers like PMMA. This interference is the building block of the observed crazed and cracked lines. The bonding chains, which adhere to the polymer's whole structure, are disturbed during some cases of these amorphous polymers [2, 21].

Arai *et al.* has proposed in the research about the slow rate of crystallization of PMMA than other transparent polymers. Because of the slow crystallization rate of the PPMA, it behaves as an amorphous component in the PVDF blend. On behalf of that result, it is estimated that crystallization of PVDF would be the same as that of crystalline/ amorphous blend. The Literature review gives an insight into the crazing phenomenon, which is related to the evaluation of environmental stresses, chemicals, solvents, and mold releases along with the changes in the type of material being produced. It also gives an insight into the propagation of craze concerning heat, pressure, and flow cooling [22, 23].

In the whole literature review, it's been noted that the work was being done on the appearance of crazing concerning mold releasing agents, solvents, chemicals, and other agents. In this study, all the environmental stresses caused by weather conditions, solvents, other chemicals, and internal stresses are studied with the molding machine parameters [8, 23, 24]. From the literature review, no single study has thoroughly investigated the preferred to melt injection molding process parameters on the crazing in PMMA.

The aim is to explore the injection molding process parameters (melting temperature, injection pressure, speed, holding pressure, and cooling time) to become more knowledgeable of the crazing phenomena in PMAA and produce high-quality motorbike headlights as the final finished product.

Experimental

Specifically, this piece of the examination presents the plan of the investigation, especially the exploration strategies and methods to be utilized. The sample size is taken, the instrument to be utilized and their approval, and the information investigation plot, which incorporates factual devices for treatment of information yielded by the investigation. In this research, prepared three types of samples by carrying three different experiments. First, samples were prepared with different parameters to find optimized injection molding process parameters. Second samples were prepared with optimized parameters without a mold releasing agent. Last but not least third group of samples were prepared with a varied amount of mold releasing agent.

All samples were then tested on main criteria to optimize the processing parameters in the automotive sector. Lux intensity, density, and crazing were three basic requirements to qualify for the final optimized sample. Moreover, service tests (vibration test, thermal cycle test, chemical test, abrasion test, falling drop test, and effect of aging) were performed to certify the sample for ultimate customer use. Finally, mechanical tests such as the tensile test, Izod impact test, Charpy impact test, and hardness test, carried out to examine the effect of optimized parameters on the inherent properties of PMMA resin. On behalf of all results, did optimize the processing parameters and mold releasing agent amount with no trace of crazing.

Sample Preparation at Different Parameters

In this research, the polymethyl methacrylate (PMMA) resins used to prepare the sample in this study was (CM-207) were purchased from Chi Mei Corporation, Taiwan. With a melt flow index (MFI) of 8.0 g/10min (238°C and 1.8 kg load) and density of 1.19 g cm^3 at 23°C. The PMMA resins were dried at 60°C for 4 hours before use. Using the same mold releasing agent as the company used Nabakem mold release R2, a Korean brand, to ease sample pieces during ejector by using it 20 to 30cm away from the mold. It is mainly composed of LPG. There are some cautions regarding Nabakem R2 mold release. Do not use it near the heater or stove, and do not keep it in place above 40°C. Spraying may not work well below 5°C. The specimens for the test were manufactured on an injection molding machine setup from Electropolymers (Pvt) Limited Molding floor.

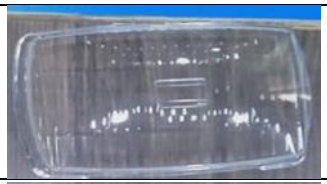
The polymethyl methacrylate (PMMA) injection molded samples (lens of motorbike headlight) were prepared. They used a plastic injection molding machine 280T (Huarong Plastic Machinery Co., Ltd., Taiwan) with a length to diameter (L/D) ratio of 23.636. The injection molding parameters are tabulated in Table-1. The injection molding parameters will be varied to explore their effects on the creation of crazing and to improve the quality of the finished product [2, 5, 11, 24].

Parameters That Being Constant

In this study, three parameters were held constant. Barrel temperature, as per rule of thumb (*Tm+50°C*) PMMA melting temperature is at 160°C. Based on melting point (*Tm*) determination and literature studied; Feed: Compression: Metering: Nozzle = 185-205: 185-205: 190-210: 195-215. Cooling time due to a substantial slow crystallization rate and without affecting production rate, 4 s was selected as cooling time. Injection speed; to control production rate, injection speed was selected 60%.

For specimen preparation, first choose the molding type, part, and cargo for the molding machine as went with the same mold, part, and molding machine as the company is manufacturing the same part to study crazing defect. Clean the mold surface to remove any film or grease particles. The PMMA resin was preheated and dried at 60^0C for 4 hours before use. Set parameters, resin melt in the barrel, and move forward. Inject the material in the mold with holding pressure shown in Table-1. Allow the mold to be cooled for about 4 sec. Eject the part from the mold. Cut the sprue and runner with the help of a knife. After that, the samples were weighed and then sent for testing. Many samples were prepared, and among them, the best samples were chosen, and on them, different tests were performed. In the automotive sector, to optimize the injection processing parameters, three basic tests qualify as the main criteria for a motorbike headlight lens. And the basic assessments are lux intensity, density, and crazing. They start with a fundamental introduction and equipment description or test setup details, followed by the test procedure and results of each test.

Table-1: Parameters in Injection Molding Process.

Sample	Picture	Parameters	
		Varied	Constant
IP70 HP65		**Holding pressure (HP) 65 kg/cm^2**	**Injection pressure 70 kg/cm^2, Injection speed 60%, Cooling time 4s, Barrel temperature ^{0}C 185-205: 185-205: 190-210: 195-215**
IP70 HP75		**Holding pressure (HP) 75 kg/cm^2**	
IP70 HP85		**Holding pressure (HP) 85 kg/cm^2**	
IP80 HP65		**Holding pressure (HP) 65 kg/cm^2**	**Injection pressure 80 kg/cm^2, Injection speed 60%, Cooling time 4s, Barrel temperature ^{0}C 185-205: 185-205: 190-210: 195-215**
IP80 HP75		**Holding pressure (HP) 75 kg/cm^2**	
IP80 HP85		**Holding pressure (HP) 85 kg/cm^2**	
IP90 HP65		**Holding pressure (HP) 65 kg/cm^2**	**Injection pressure 90 kg/cm^2, Injection speed 60%, Cooling time 4s, Barrel temperature ^{0}C 185-205: 185-205: 190-210: 195-215**
IP90 HP75		**Holding pressure (HP) 75 kg/cm^2**	
IP90 HP85		**Holding pressure (HP) 85 kg/cm^2**	

Result and Discussion

Lux Intensity

The aggregate sum of energy of all the light produced is known as "luminous flux." A generally known term for measuring light intensity is "Lumen." Candela is the basic unit of luminous intensity. Quantitatively 1 candela/ steradian is termed to be one lumen. The measurement of light, how many Lumens are coming in contact with the surface is the main factor known, which is termed as LUX. It can be defined as 1 lumen / sq meter. LUX test will be performed on voltage unit and LUX measured by LUX meter following JIS- D5500 guidelines.

This test was performed in a dark room to check the brightness of the sample lamp properly. LUX intensity test consists of assembled sample metal jig to mount the sample in the straight direction. It has a voltage meter to regulate voltage and current. LUX meter measures the amount of light which is also called brightness, within the environment due to the sample lamp. Assembled headlight with lens sample fixes on LUX intensity test equipment via jig. Samples were subjected to 12 volts, and a standard distance of 10m was maintained. Finally, measure the LUX intensity on the LUX meter, mounted on the wall at 180^0C to sample. Standard Lux of Targeted Lamp is 27200 ± 30% cd (Minimum = 19040 cd and Maximum= 35360 cd). An average of three test samples was reported for this test [2, 12, 17].

Find optimized parameter of injection pressure 70 kg/cm^2 and holding pressure 65 kg/cm^2, as in Fig 4, find LUX within the standard range only in one sample, IP70HP65. All other samples have Lux intensity above or below the standard or required Lux intensity.

Relative Density

Relative density or specific gravity determines the density of the material to the density of reference material. It is the ratio of the density of the substance to the density of water. Mostly for liquid, it measured concerning water density (at 4°C), and for gases, it measured concerning air density (at 20^0C). The test will be performed following ASTM D792, ISO 1183. The 3cm square sample specimen was placed on a weighing machine to measure the weight in the air. The same sample was weighed when immersed in distilled water at 23°C with the help of a sinker and wire to hold the sample completely submerged. Density was calculated by [2, 17];

$$Relative\ density = a/[(a + w) - b] \qquad (1)$$

where; a = Mass of sample in air, b = Mass of sample in water, w = Mass of a completely immersed sinker and partially immersed wire. The standard relative density of the sample is 1.2 ± 0.02 (mentioned in the material specification sheet). An average of three test samples was reported for this test.

Once again, found the same optimized parameter of injection pressure 70 kg/cm^2 and holding pressure 65 kg/cm^2, as only that sample (IP70HP65) has a relative density within the standard range, Fig. 5. All other samples have relative density above or below the standard or required density value.

Crazing

The network of fine cracks on the surface due to excessive stress, which leads to microvoids formation, is called crazing. Crazing was inspected visually after producing samples with nine different parameters mentioned in Table-1. Random crazing was observed in optimized injection pressure (70kg/cm^2) and holding pressure (65kg/cm^2). No trend was observed in crazing; see in Fig. 6. Crazing was observed above the permissible limit (≤ 2%) with optimized process parameters [7, 15].

Sample Preparation without Mold Releasing Agent

As found random crazing in samples, without any trend in the previous experiment so observe the things and parameters which were use time to time in the process and found mold releasing agent was the one thing which operator used after 4 to 5 shots. And maybe it was the reason behind the occasional crazing. So, prepared the samples with an optimized injection molding machine with injection pressure 70 kg/cm^2, holding pressure 65 kg/cm^2, injection speed 60%, cooling time 4 sec, barrel temperature ^{0}C 185~205: 185~205: 190~210: 195~215, without mold releasing agent.

The PMMA resin was preheated and dried at 60°C for 4 hours before molding. Then set the parameters at optimized values and start melting the resin in the barrel by moving the barrel forward; melted resin was injected into the mold, then allowed the mold to cool down and eject the part. Without using mold releasing agent tried 50 sets of shots. But all samples observed were broken during ejection due to no use of mold releasing agent; samples stick with mold and crack at the time of ejection as all samples were broken, not do any tests on these samples [10, 19].

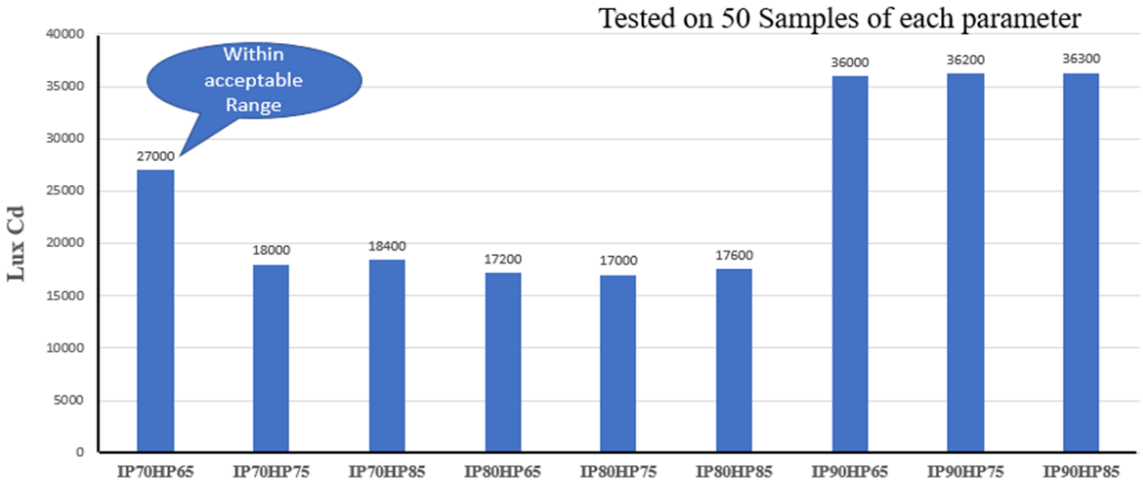


Fig. 4: LUX verse nine samples with different parameters.

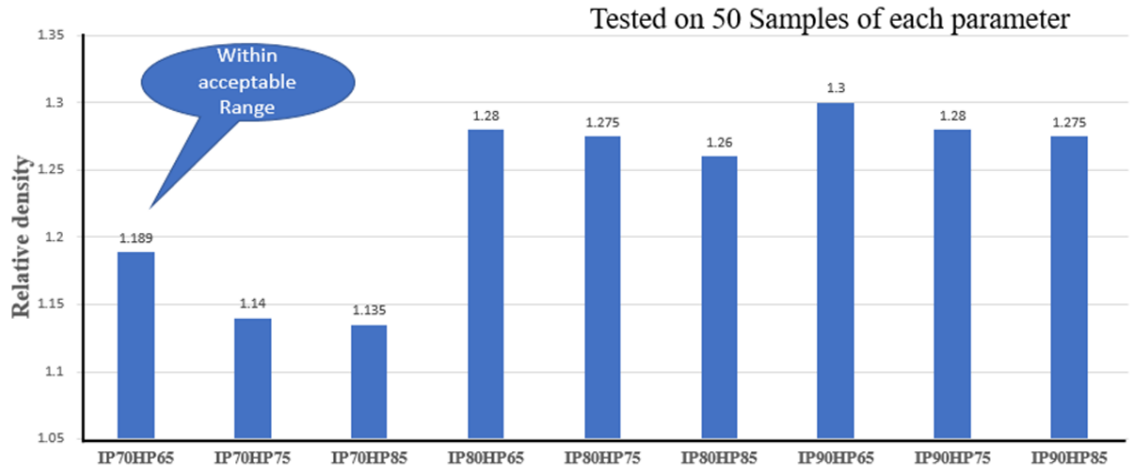


Fig. 5: Relative density verse nine samples with different parameters.

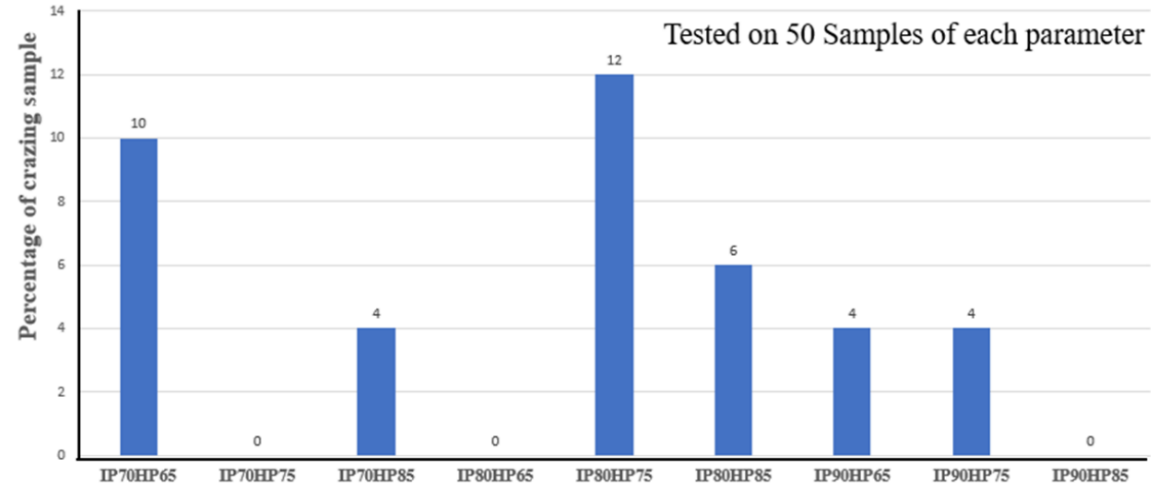


Fig 6: Percentage of crazing verse nine samples with different parameters.

Table-2: Optimized Parameters.

Parameters	Value	Unit
Barrel zones temperatures (Feed: Compression: Metering: Nozzle)	**185-205: 185-205: 190-210: 195-215**	**^{0}C**
Injection pressure	**70**	**kg/cm^2**
Injection speed	**60**	**%**
Holding pressure	**65**	**kg/cm^2**
Cooling time	**4**	**s**
Amount of mold releasing agent	**1.18**	**g**

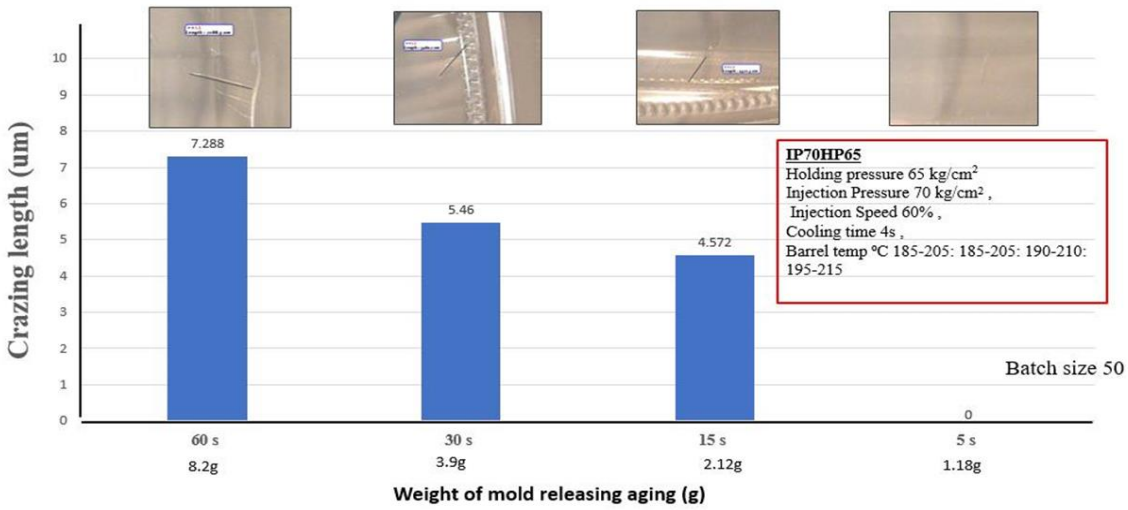


Fig. 7: Effect of mold releasing agent on crazing length.

Sample Preparation with Varied Amount of Mold Releasing Agent

After finding all samples broken during ejection with no mold releasing agent, make the samples by varying the amount of agent with optimized parameters as shown in Table-2. The parameters include injection pressure 70 kg/cm^2, holding pressure 65 kg/cm^2, injection speed 60%, cooling time 4s, barrel temperature °C 185-205: 185-205: 190-210: 195-215 and injection molding machine 280T (Huarong Plastic Machinery Co., Ltd., Taiwan) with PMMA Resin CM-207. It cannot measure the weight of mold releasing agent during spray, so vary the spray contact time and measure the average weight and fix it as below four sets. Time: 60s – Weight 8.2g, Time: 30s – Weight 3.9g, Time: 15s – Weight 2.12 and Time: 5s – Weight 1.18g.

So, as a result (Fig. 7) found optimized injection molding parameters of IP70HP65 and amount of mold releasing as get crazing free sample with 1.18g of mold releasing agent after every four shots.

Service Testing

The automotive industry is subject to a host of regulations and standards governing the safety, quality, and performance of its product. So, after optimizing the parameters, need to test the samples with service testing to fulfill customers' quality assurance and compliance is; vibration test, thermal cycle, falling drop test, abrasion test, the effect of chemical and effect of aging on crazing.

Vibration Test

A vibration test is performed to ensure product performance under extreme conditions such as jerks due to bad road conditions or loose headlight mounting, which leads to the propagation or creation of crazes. A shock test is the sharp transfer of energy into a mechanical system to check the capability of the sample to survive a drop, hit, impact or fall. A vibration test will be performed on vibration and shock tester following JIS-JSA B 0153: 1985 guidelines. This test was performed on a vibration tester with a spring system to execute the vibrational motion according to the given signal from the frequency regulator box. It also has a sample mounting jig that clamps the sample firmly to prevent slipping during the test. The vibration is done and shock test on signal equipment by just changing the frequency value.

Assembled headlight with lens sample fixes on vibration test equipment via jig. Samples were subjected to two different vibration frequencies of 33 Hz and 67 Hz for 1 hour at 20 °C—the 33Hz for vibration test and 65Hz for shock test. An average of three test samples was reported for this test. The samples were further observed to report the effect of vibration

cycles on crazing—fortunately, no trace of crazing on samples before and after this test [9, 16].

Thermal Cycle Test

In thermal cycle test is to check the ability of the sample to resist two extreme conditions and will observe the effect of heating and sudden cooling on the sample. This cycle will be performed to determine its effect on-craze propagation or diminishing. This test consists of two chambers (heating and cooling). These chambers should provide and control the specified temperature and cycle timing in the working zone(s).

The samples should be placed in position concerning the air stream; there is no obstruction to airflow across for each sample in both chambers. To place the sample in a heater at 70^0C for 1 hour. Adjust the temperature timer and vacuum the oven/ heater. Then quickly transferred the samples to the refrigerator at 0^0C for 1 hour. After this cycle, Place the sample to settle at room temperature then the sample was observed to report the effect of the heating-cooling cycle on crazing. This test shows that crazing remains the same on that spot and after 24 hours [3, 20, 21].

Falling Drop Test

The impact test will be performed to determine the impact strength or toughness of the motorbike's headlight, that is, its resistance to crack creation and propagation. It is the best way to check whether a product is suitable for use in environments where this kind of impact might happen—also called the free-fall drop test. To see the effect of the test on crazing propagation or generation observed the progressive failure of the lens sample. The test will be performed following JIS D 5500-1995. This test was performed on a free-falling impact tester which has a platform with a clamping jig to fix the sample firmly. It also has a scale of 2m attached vertically to the jig platform. Last but not least, 40cm metal ball with 50g weight.

The test sample was placed on the machine platform for the sample with the lens facing up and fix the lens sample with jig probes. A sphere of diameter 23 mm and weight 50g dropped on the lens's head from a distance of 40 cm approx. Sphere dropped along the mechanical axis of the lamp. An average of three test samples was reported for this test. The samples were further observed to report the effect of the impact test on-craze appearance and propagation. They did not find any sign of crazing on the sample before and after the falling drop test [2, 24].

Abrasion Test

The abrasion is the action of scratching, wearing down, or rubbing away. The abrasion test is carried out to test the hardness property of the sample. The principle of the abrasion test is to find the percentage wear due to relative rubbing action between the abrasion pad and the testing sample. It was also performed to check the abrasion resistance of the samples against the abrasion pad. The abrasion test was easy to be performed; it just needs sandpaper of 100 grit with dimensions of 25 x 100 mm^2 and a stopwatch along with a testing sample.

Lens samples were weighted before the test. The sandpaper (abrasion pad) was rubbed manually on the testing sample for 1 minute with normal force. The abraded samples will be collected and weighed. The difference between the initial weight and the final weight of the specimen will tell us how much material is lost in the abrasion test. Ten test samples were reported for this test for authentic results. The abraded sample was also examined for abrasion resistance and crack appearance. Optimized samples show different weight change values, as do the abrasion test manual, Fig 8. It was found that all samples under allowable abraded weight in grams that is 0.45g [7, 11].

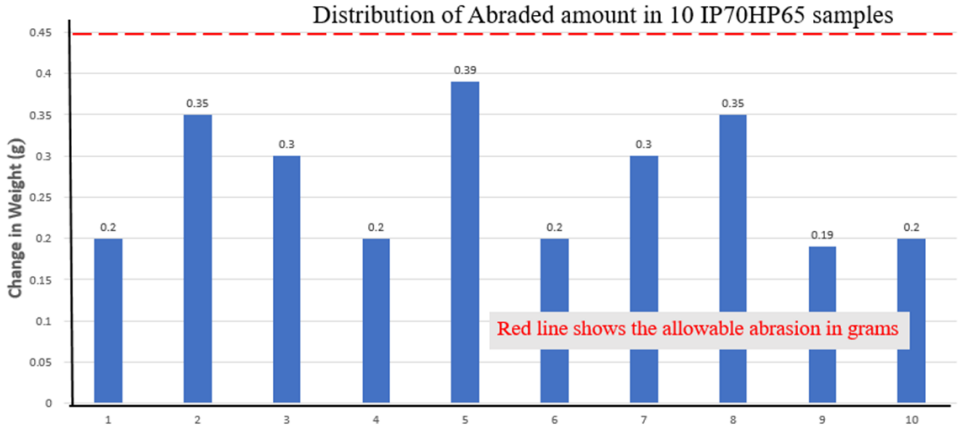


Fig. 8: Samples verse change in weight during abrasion test.

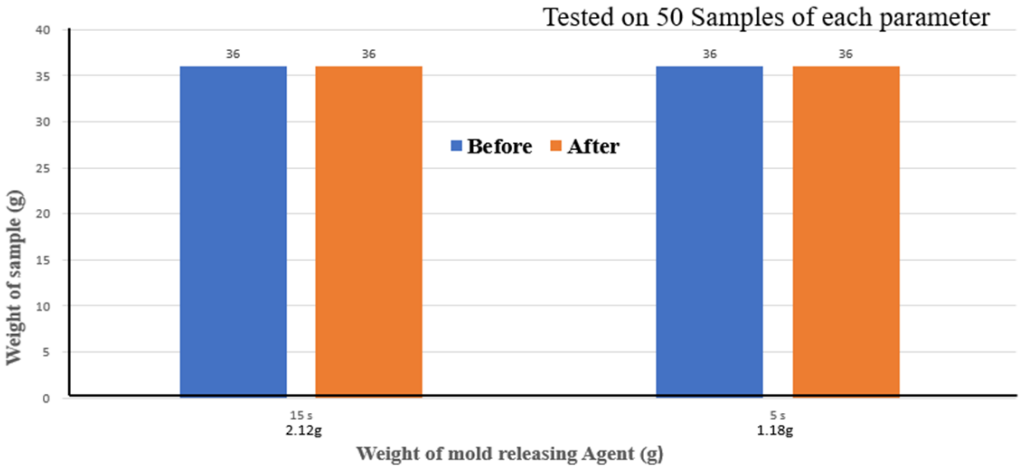


Fig. 9: Weight of mold releasing agent verse sample's weight before and after the chemical test.

Chemical Test

The chemical resistance of the headlight was determined against the lubricant chemical (Total Azolla ZS 46). The samples exposed to chemicals were compared with unexposed headlights. To assure better performance of the samples, they should not show any color pickups, deterioration of bonding material, fractures, and color bleeding due to exposure to the test fluids. This test needs a lubricant chemical (Total Azolla ZS 46) used in a molding machine and one glass beaker with a time watch. Fill the beaker with lubricant. The weighted sample placed the lens in the filled beaker and left it for 24 hours. After 24 hours, again weight and check the change in weight which will tell us how much chemical is absorbed. This research use samples with optimized parameters with 1.18g and 2.12g mold releasing agent to compare the results. An average of three test samples was reported for this test for authentic results. The samples were further observed to report the effect of the chemical on-craze appearance and propagation. In this test, compare samples weight 2.12g mold releasing agent (sample with crazing) and optimized sample with 1.18g mold releasing agent with no crazing. It found no change in weight of both the samples after and before this chemical test for 24 hours, as shown in Fig 9 [10, 16].

Effect of Aging on Crazing

Crazing is a time-dependent defect that propagates the crazing length. It wants to know whether the sample with no trace of crazing can show the crazing traces with time or not. The samples were observed at the manufacturing time, then placed optimized sample at room temperature under normal conditions for two months. Samples were observed after 24 hours, 48 hours, one month, and two months. An average of three test samples was reported for this test for authentic results. The samples were paid attention, the effect of time on-craze appearance and propagation. There was no trace of crazing after 24 hours, then check it again after 48 hours and found same then after one month and two months did not find any kind of crazing in samples.

Mechanical Testing

After the service test, to see whether the optimized parameters of the injection molding process affect the inherent properties of PMMA or not. Mechanical testing employs various strength tests that can determine the suitability of a material for the intended application. The mechanical test performed are; tensile test, Izod impact test, Charpy hardness test.

Tensile Test

The tensile test is an important test to check the properties of plastic. The tensile test gives us the mechanical properties of the materials. It is a destructive test that gives the maximum force that plastic can withstand under tensile loading. The tensile test is performed on a dumbbell /flat specimen. The test was be performed following ASTM D638. Tensile test performed on the universal testing machine, which has tensile grip jigs and firmly clamps the optimized sample. Cut the sample in stripes for this tensile test. The exact dimensions are Length 80mm and width 12mm. Load the specimen into tensile grips (gauge length =60mm). The sample was gripped by a jig and began the test by separating tensile grips slowly at a constant rate of speed until it broke. Speed is 20mm per minute. End the test after sample break (rupture). Around ten samples have performed this test to find the distribution; see Fig 10 [3, 13, 18, 20].

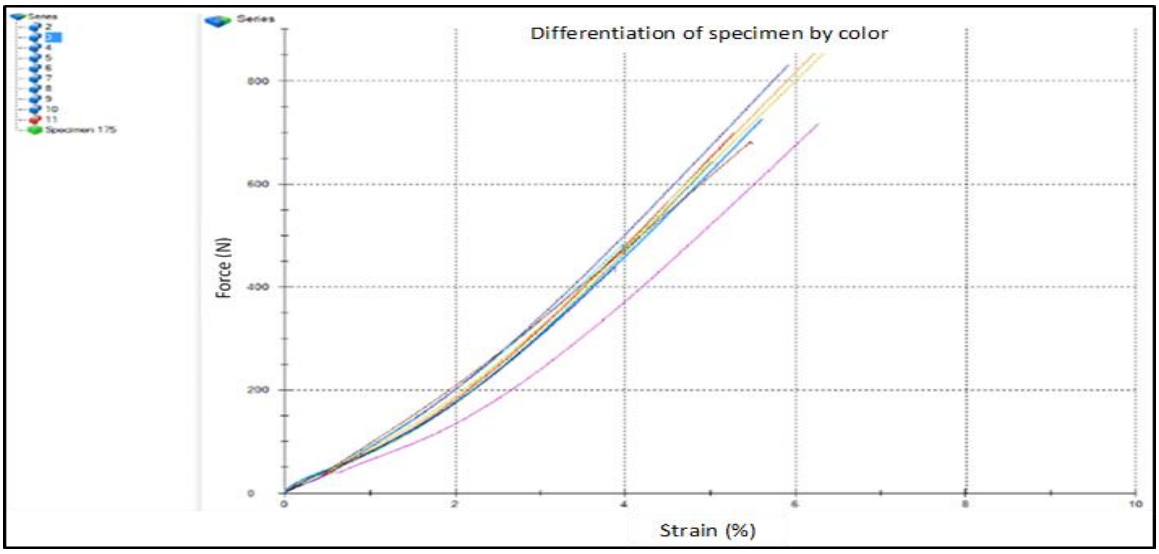


Fig. 10: Strain percentage verse force on ten samples.

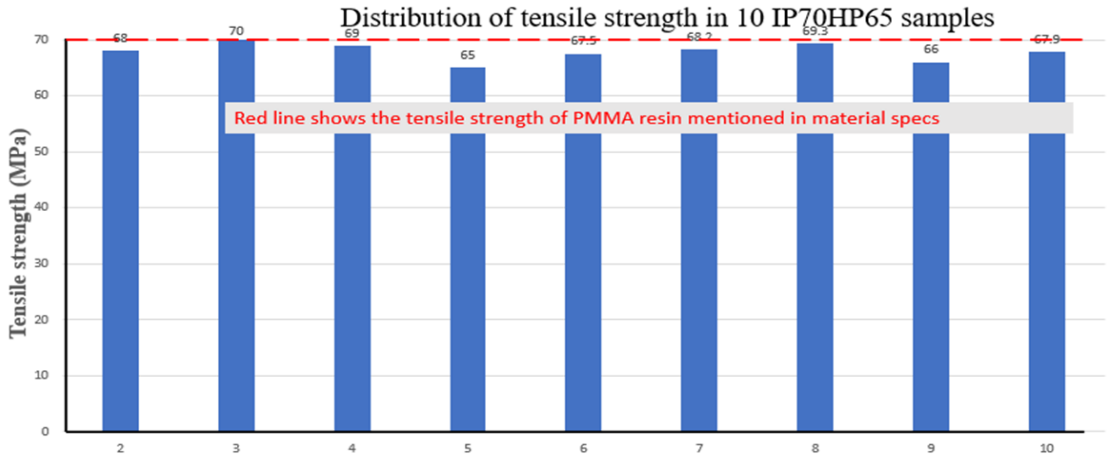


Fig. 11: Tensile strength distribution for ten samples.

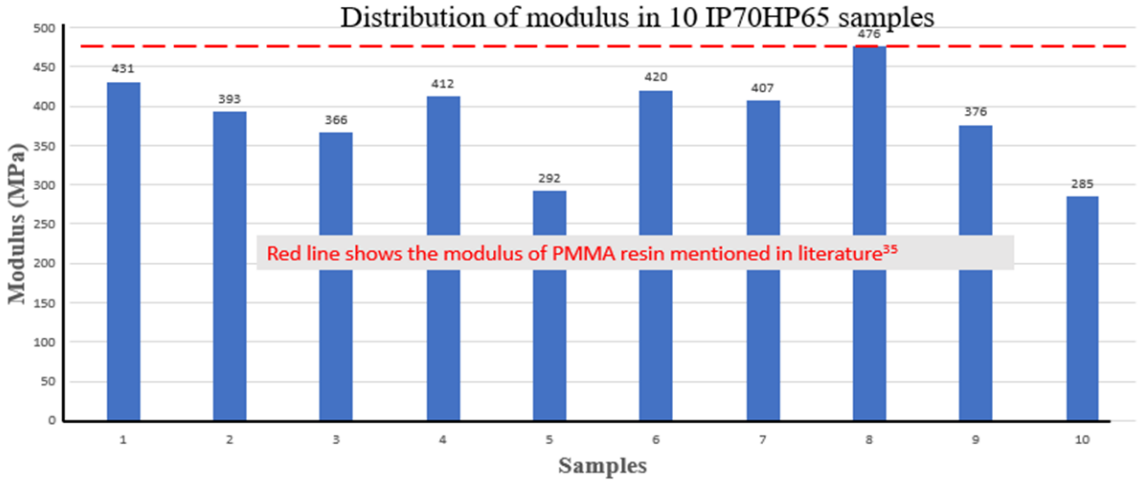


Fig. 12: Modulus distribution for ten samples.

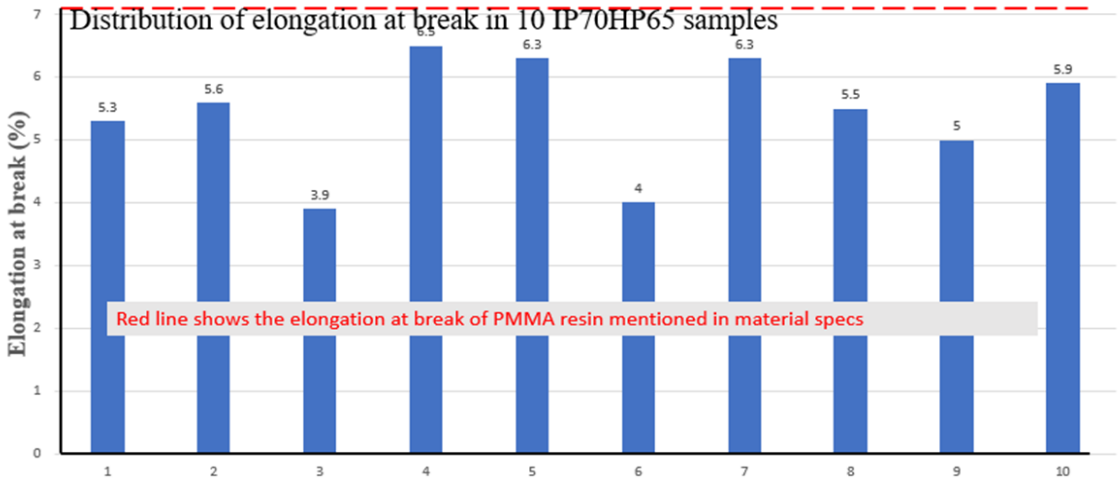


Fig. 13: Elongation at break (%) distribution for ten samples.

It was concluded from Figs 11,12, and 13 that the inherent tensile properties of PMMA do not disturb due to fixing the processing parameters as found tensile strength, modulus, and elongation at break nearly same as it mentioned in material specs of PMMA or literature.

Izod Impact Test

Izod impact test is used to evaluate the relative toughness or impact toughness of materials and is mostly used in quality control applications. Izod normally refers to a notched specimen impact. Impact measures the energy required to break a specimen by striking a specific size bar with a pendulum. Flat samples were used to perform this test, following ASTM D256. RAY-RAN Universal pendulum impact system is used to measure Izod impact with an Izod hammer of weight 0.905kg. It has a jig to hold the optimized sample in the vertical position and is supported by the lower end of the sample. In this test, a flat strip of length 60mm and a width of 12mm was used. One end is fixed on the jig in a cantilever position. Pivoting arm with the Izod hammer is raised to a specific height and then released. The arm swings down with a velocity of 3.46 m/s and hits the sample, and breaks it. Around 12 samples have performed this test to find the distribution. From Fig 14, all samples have lower energy absorbed than the resin should inherently absorb the energy [2, 7, 15].

Charpy Impact Test

The Charpy impact test is performed to evaluate the resistance to breakage by flexural shock. This test is also called the Charpy V-notch test. Impact measures the energy required to break a specimen by striking a specific size bar with a pendulum. Flat samples were used to perform this test according to ASTM D6110. RAY-RAN universal pendulum impact system measures Charpy impact with an Izod hammer of weight 0.43kg. It has a jig to hold the optimized sample in a horizontal position and is supported from both samples ends. In this test, a flat strip of length 80mm and width 12mm. Both ends are fixed on the jig in a horizontal position. Pivoting arm with Charpy hammer is raised to a specific height and then released. The arm swings down with a velocity of 3.46 m/s and hits the sample, and breaks it. Around seven samples have performed this test to find the distribution. Fig 15 found all samples have higher energy absorbed than the resin should inherently absorb the energy [17, 23].

Hardness Test

In mechanical engineering, to determine the hardness of a material to deformation, use indentation hardness to evaluate the material's property. A hardness test is done on the sample to check how much the prepared sample shows resistance towards localized penetration. It gives us the guideline for defining the samples' application, using a full sample for this testing. The test was be performed following ASTM D785. Hardness test performed on Shore D hardness tester. Shore D hardness is a standardized test measuring the depth of penetration of a specific indenter. It is used for non-metallic hard samples, and the optimized sample was laid on the platform of the tester. An indenter was pressed into the sample's surface, tested under a specific load for a definite time interval. The penetration of the durometer indenter foot determined the hardness value into the sample. Around five samples have performed this test to find the distribution. Fig 16 shows that hardness shore D values do not change much with processing parameters. It is the same as mentioned in the material specs [3, 20, 22, 24].

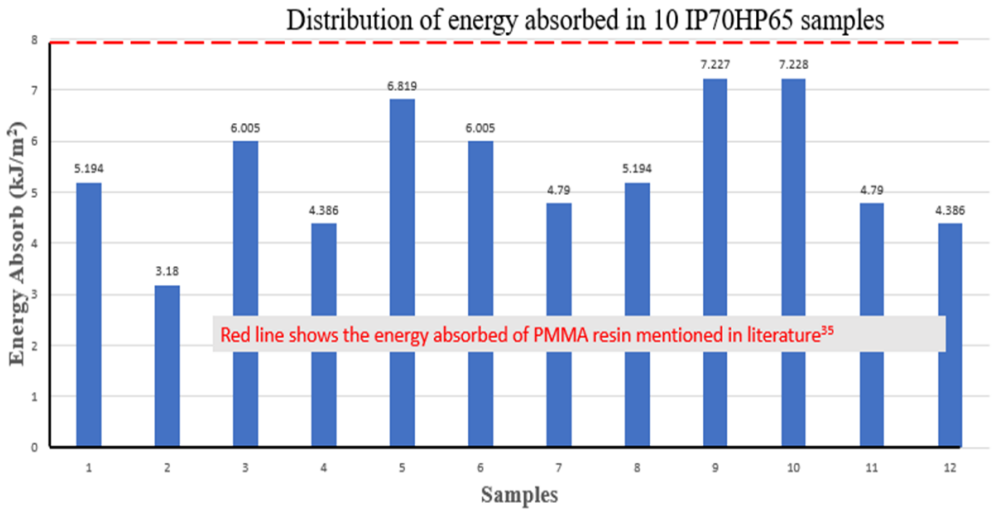


Fig. 14: Distribution of energy absorb for 12 samples in Izod impact test.

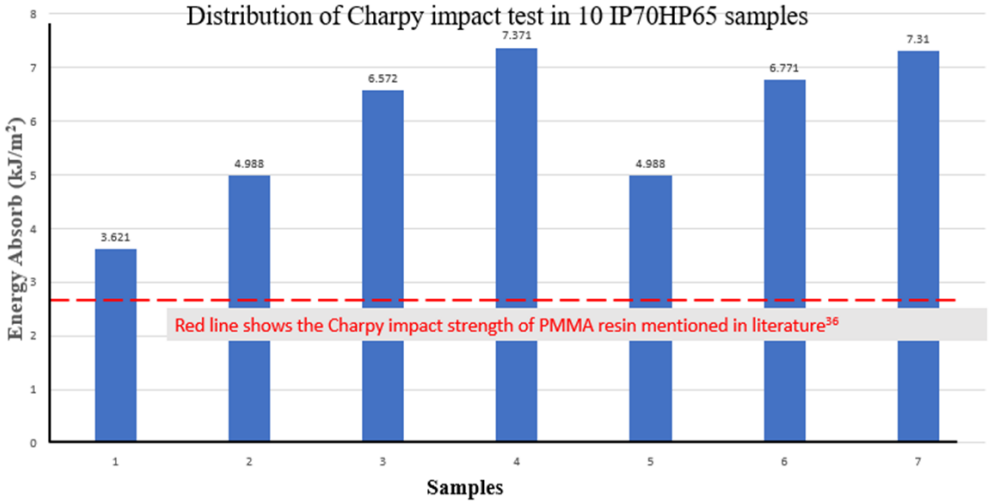


Fig. 15: Distribution of energy absorb for seven samples.

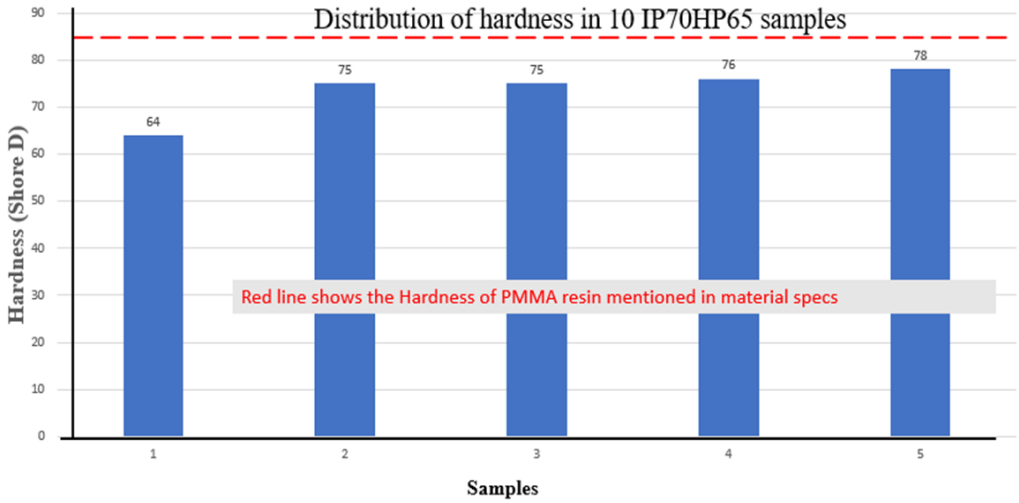


Fig. 16: Distribution of hardness value for five samples.

Conclusion

The effect of injection pressure and holding pressure in the range of 70-90 kg/cm^2 and 65-85 kg/cm^2, respectively, was varied to prepare the headlight lens of motorbikes. The injection process parameters were optimized at injection pressure 70 kg/cm^2, holding pressure 65 kg/cm^2, and other constant parameters. The optimized parameters had required lux and density. However, it showed occasional crazing in samples about 10 % of the total production (50 pieces). The mold releasing agent was optimized at an exposure time of 5 sec (1.18g). The optimized injection parameters and the mold releasing agent showed < 2 % crazed samples and are acceptable in a production line. The optimized samples did not show any mark of crazing after service life testing. Mechanical testing showed no substantial changes in the inherent mechanical properties of the base resin after injection molding, at least at optimized parameters.

List of Abbreviations

PC = Polycarbonate, PMMA = Poly Methyl Methacrylate, PVDF = Polyvinylidene fluoride, Tm = Melting temperature, IP70HP65 = Injection pressure 70kg/cm^2 and holding pressure 65 kg/cm^2, IP70HP75 = Injection pressure 70kg/cm^2 and holding pressure 75 kg/cm^2, IP70HP85 = Injection pressure 70kg/cm^2 and holding pressure 85 kg/cm^2, IP80HP65 = Injection pressure 80kg/cm^2 and holding pressure 65 kg/cm^2, IP80HP75 = Injection pressure 80kg/cm^2 and holding pressure 75 kg/cm^2, IP80HP85 = Injection pressure 80kg/cm^2 and holding pressure 85 kg/cm^2, IP90HP65 = Injection pressure 90kg/cm^2 and holding pressure 65 kg/cm^2, IP90HP75 = Injection pressure 90kg/cm^2 and holding pressure 75 kg/cm^2, IP90HP85 = Injection pressure 90kg/cm^2 and holding pressure 85 kg/cm^2, Cd = Candela, ASTM = American society for testing materials.

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Conflicts Of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

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