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Article

Study on Material Selection of Bicycle Headlight Lamp Housing

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Abstract: With the rapid advancement of energy-saving light emitting diode (LED) lamps, LEDs have replaced traditional light sources with filaments known for their high energy consumption. LEDs also allow the persistent issue of providing a continuous and stable power supply for bicycles to be resolved. We delved into the characteristics of six commonly used materials for crafting car lamp housings and explored the advantages and disadvantages of the use of the materials in the production of car lamp housings. To circumvent the expenses associated with the distribution design and manufacturing of light sources, we employed low-cost general-purpose household LED lamps as the light source in designing the headlight of the bicycle. We conducted a series of experiments to assess the lamps' impact resistance, weather resistance, heat resistance, chemical resistance, and overall durability. Additionally, we measured the specific gravity of the six materials and tested their respective heat distortion temperatures. Finally, market research was performed to ascertain prevailing prices and formulate production recommendations that take into account cost considerations.

Keywords: LED, BMC, PP, PA, ABS, PC, PPC, Bicycle headlight, Lamp housing design

1. Introduction

Since 1869, when the British defined the modern bicycle as a “two-foot-driven mechanical device”, it has undergone over two hundred years of evolution, resulting in a wide range of uses such as sports, competitions, entertainment, and leisure. Especially during the COVID-19 pandemic, the demand for bicycles as a means of independent mobility has grown, driven by concerns for public health and safety. The introduction and rapid advancement of energy-saving light emitting diode (LED) lamps have significantly reduced the power consumption required for the lighting lamps of the vehicle. This prompts various types of cars and electric vehicles to actively explore the incorporation of LED technology as their light source. Conversely, bicycles that require a reduction in load requirements, have benefited from the adoption of LEDs, as they replace traditional filament light sources due to their high energy consumption. Consequently, equipping the bicycle with lighting has become easier than ever before.

Major bicycle light manufacturers have reimagined their brand lamps to incorporate LED light sources and have also developed various lighting auxiliary equipment such as taillights and warning lights. Additionally, numerous researchers are actively investigating and designing LED lamps with innovative light sources with secondary lenses and reflector lamp housings. The objective of these tasks is to accommodate the distinctive light distribution methods of LED light sources, thus meeting the diverse requirements in different countries for bicycle lights. However, there is still a dearth of research reports highlighting the selection and manufacturing of bicycle lamp housings. Owing to the dominance of a few well-known international bicycle manufacturers, bicycle headlights adhere to their specifications. By employing low-cost, general-purpose LED lamps as light sources and designing the lamps based on these sources, it becomes possible to eliminate the design and manufacturing costs associated with the light source distribution. This, in turn, enables the low-cost design and production of bicycle headlights. The purpose of this research is to investigate the characteristics of several materials suitable for crafting lamp housings, explore their application in bicycle headlight design, and present a cost-effective manufacturing method for bicycle headlights. We selected six commonly used materials in the market and described their properties, advantages, and disadvantages as follows when used in the manufacture of car lamp housings [1–3].

(1) Bulk molding compound (BMC), a thermosetting plastic, is made up of glass fibers, fillers, and trace additives combined with UP (unsaturated polyester). It has advantages such as affordability, high heat resistance, dimensional stability, and a visually appealing finish achieved through vacuum aluminum evaporation (with primer). However, there are drawbacks associated

with BMC, including its high specific weight, inability to be recycled, costly mold production, the requirement of a specialized injection machine, high mold temperatures, the need for refrigeration of raw materials, and the necessity of complex pre-treatment before vacuum evaporation.

(2) Polypropylene (PP) is commonly used as the base material for the rear lamp. To enhance its heat resistance and rigidity, talc is added. The main advantage of PP is its affordability and higher heat resistance compared to ABS. However, it has drawbacks. The material's surface lacks brightness and exhibits poor adhesion with vacuum parts. To solve these, a primer (PP surface treatment agent) must be added to the vacuum primer used for improved adhesion.

(3) Polyamide (PA) is a thermoplastic crystalline plastic that benefits from the addition of a reflector material to enhance its heat resistance and rigidity. To achieve a smooth surface, the mineral powder form of PA is commonly used as the primary material. While the incorporation of glass fiber significantly improves heat resistance and rigidity, it may result in floating fibers that adversely affect the material's appearance, unless the mold temperature is high enough to overcome this issue. PA possesses the advantages of affordability and high heat resistance. However, it tends to absorb moisture easily and exhibits a high shrinkage rate, leading to post-shrinkage after vacuum evaporation and a high defect rate in vacuum evaporation parts.

(4) Acrylonitrile butadiene styrene (ABS) is a thermoplastic, non-crystalline plastic composed of three types of polymers. By varying the composition ratio, ABS exhibits various characteristics. ABS, particularly heat-resistant ABS (CM777D), is commonly used as the base material for rear lamps. It has advantages such as a high surface gloss, excellent coating and electroplating properties, good mechanical strength, and heat resistance compared to other general-purpose plastics. However, there are a few disadvantages to consider. The base color of ABS is yellow, so finished products often require dyeing. ABS also has poor weather resistance, and in some cases, the heat resistance may not be sufficient when used as the base material for rear lamps.

(5) Polycarbonate (PC) is a thermoplastic non-crystalline material and is known for its transparency. When used in reflectors, the raw material is transformed into an opaque color to prevent light loss, while still is used for its transparent properties. The advantages of polycarbonate include the lack of filler additives, resulting in a bright surface for molded products. It exhibits excellent adhesion with vacuum evaporation due to poor solvent resistance (with primer spray). Additionally, PC has low specific gravity, high rigidity, and excellent impact resistance at room temperature. However, there are a few drawbacks to consider including relatively low heat resistance, approximately 135°C. The price is slightly higher compared to other materials, and the forming process can be challenging, requiring tempering to alleviate internal stress in the final products.

(6) PPC, or heat-resistant polycarbonate, is a non-crystalline thermoplastic material. While it shares similarities with PC such as high heat resistance (around 165°C) and a glossy surface finish, PPC's impact resistance is inferior to that of PC. Furthermore, PPC is filler-free. Although PPC offers benefits such as exceptional heat resistance and visually appealing molded products, it has drawbacks such as relatively higher manufacturing costs compared to other plastics and limited impact resistance, particularly in vacuum applications.

We comprehensively compared six different materials and analyzed their shrinkage, heat distortion temperature, and specific gravity. Additionally, we tested these materials by measuring impact resistance, heat resistance, chemical resistance, and deterioration resistance. Based on the results, we designed a series of lamps and discussed the underlying design principles and distinctive features. Furthermore, we evaluated the cost of raw materials and provided recommendations for material selection [4,5].

2. Materials and Methods

To conduct an impact resistance test on lamps, we employed the T-MACHINE model TMJ-9724, a specialized impact testing machine. The test was carried out at room temperature with the following procedure.

(1) Positioning the lamp: the lamp was tested with the impact testing machine on which the test product was laid perpendicular to the machine.

(2) Setting up the impact testing machine
- Activating the frequency converter by pressing the designated button
- Adjusting the rotary knob on the inverter to achieve the desired impact frequency of 750 rpm
- Setting the impact amplitude to 3.2 mm
- During the impact test, the tachometer and frequency regulator displayed their values.

(3) Timer setup: Configuring the timer to the required time duration, which in this case was 60 min.

(4) Conducting the impact test for the specified duration.

(5) Visual inspection
- After completing the test, the lamp was examined visually.

- Ensuring that none of the components were loose, cracked, or exhibiting any signs of damage.
- The lamp must not produce any abnormal noises when gently shaken.

It is important to adhere to these instructions to obtain accurate and reliable results from the impact resistance test. To perform a heat resistance test on lamps and lanterns, the following procedure was used.

(1) The tested lamp was placed in a drying oven, the Libaozhen Enterprise model: DR-2 at a high temperature.
(2) The lamp was loaded inside a drying oven to mimic the conditions in which the lamps and lanterns were used.
(3) A lighting machine, the iron T-MACHINE brand, model: TMJ-9730 was used with the necessary power supply for lighting the lamp.
(4) The power supply was connected to the lighting machine and lit the lamp for 8 h to allow for an adequate evaluation of the heat resistance of the lamp at a high temperature.
(5) After the 8-hour test, the lamp was carefully removed from the drying oven.
(6) A visual inspection of the lamp's appearance was conducted to ensure no signs of browning, melting, or burning. If any of these indications were, it suggested a failure in heat resistance.

Environmental requirements for testing included a temperature of 25 ± 3 °C and a relative humidity of 60 ± 20%. The testing method was as follows. The surface of the lamp and the junction with the light source were cleaned in the aforementioned test solution (2 ounces) using a soft cotton cloth of 6 in^2. The surface was wiped to the left and to the right (applying even pressure). The tested lamp must be wiped within 5 s after the cotton cloth was soaked with the test solution to evaluate the chemical resistance. After the test, there must be no changes or abnormalities on the surface of the object, and the coating layer must not peel off. The weather resistance of the lamp was tested in a programmable temperature and humidity chamber (the T-MACHINE brand, model: TMJ-9712). In the temperature range of -40 to 80°C, the usage conditions of the lamps were simulated at high and extremely cold temperatures. Lamp durability was tested using a salt spray cabinet tester (the SST-A model from Holy Instrument Co., Ltd). Three solutions were prepared: solution A (160 g sulfuric acid + 15 L distilled water), solution B (152 g potassium + 15 L distilled water), and solution C (464 g NaCl (salt) + 15 L distilled water). The lamp was placed in the water tank containing the prepared solution, and the spray pressure was set to 0.6−1.5 bar. The temperature inside the test chamber was maintained at 35°C. After 24 h of testing, the lamp was removed and inspected for corrosion and rusting. Finally, the specific gravity of the six materials was measured using a hydrometer to determine the temperature of the thermal deformation of the materials using a hot air gun. Since the percentage of shrinkage was relatively small, we referred to an industrial standard table for the shrinkage percentage.

3. Results

The materials used for testing included BMC, PP, PA, ABS, PC, and PPC (heat-resistant grade PC).

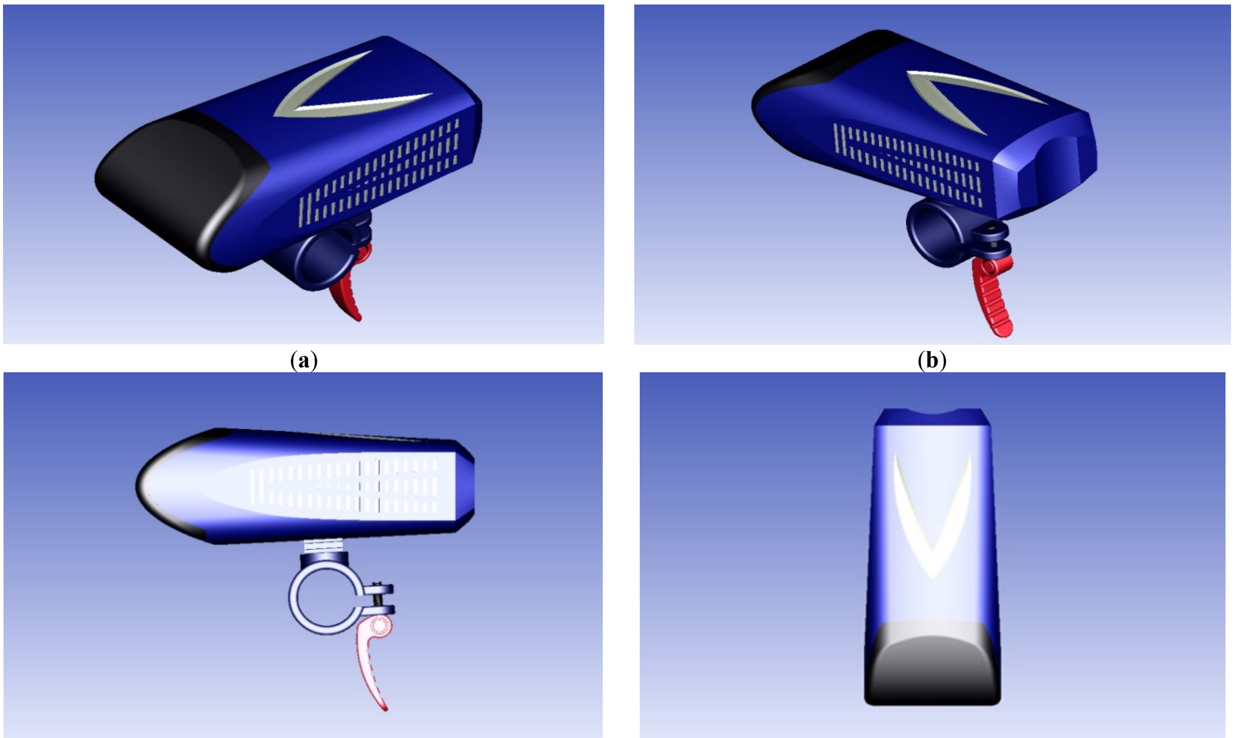
- An impact testing machine at 750 RPM with an amplitude of 3.2 mm in 1 h was used to test different materials. No embrittlement or damage was observed for all materials.
- The materials were placed in a drying oven to simulate the installment on a vehicle. The materials were lit using a lighting machine to evaluate their heat resistance at a high temperature. The heat dissipation and space constraints slightly affected the results of the lighting function, especially for LED light sources, which were low-power energy-saving lamps designed with heat dissipation considerations. After lighting, the lamps were visually inspected, and no yellowing or melting was observed. In the experimental tests of traditional light sources, the temperature exceeded 150°C, indicating that PP, ABS, and PC materials experienced yellowing and melting.
- When the materials were placed in high and extremely low temperatures to mimic the actual use, all materials passed the weather resistance test.
- The materials successfully passed the chemical resistance test using weather-resistant gasoline, kerosene, and tar remover.
- None of the materials exhibited corrosion or rusting when exposed to the three prepared test solutions.

As we used commercially available light sources and materials, the photometric values, light distribution, beam pattern, and heat dissipation characteristics of the light sources were already fixed. Thus, we focused solely on designing a lamp housing to encapsulate the light source and prevent electrical shorts. Since bicycles are used outdoors, it is necessary to consider water resistance, secondary heat dissipation between the light source and the lamp, and most importantly, the overall center of gravity when the lamp is integrated with the light source. The weight of the commercially available light source was altered from the original design's center of gravity as it was important to avoid the change of the center of gravity with the lamp on a bicycle.

Once the lamp housing design was completed, we designed the lamp mount to secure the lamp housing. Although this component is small, bicycles have limited contact areas for lamp attachment being different from vehicles. The headlights of the vehicle have larger contact areas with the vehicle body, making it easier to secure and align the lamps. On the other hand, bicycle lamp mounts are typically fixed on a cylindrical surface. Additionally, the suspension system on bicycles is not as effective as that of the vehicle, bicycle lamps must be designed to withstand vibrations and external forces. Thus, when selecting materials for the lamp mount, durability and robustness are essential considerations. Furthermore, in the design. The ease of installation to ensure convenience for users must be prioritized.

Based on these considerations, we designed several lamp mounts, including a bottomless dual-screw lock buckle, a single-screw lock buckle, and a quick-release buckle. The most common mount design is the groove-type mount. However, if this type of mount is made of non-metallic materials, it is structurally fragile and vulnerable to road conditions. Therefore, we applied the materials in the analysis and research of lamp designs.

Figs. 1(a) and 2(a) depict the oblique front view, Figs. 1(b) and 2(b) show the oblique rear view, Figs. 1(c) and 2(c) represent the side view, and Figs. 1(d) and 2(d) display the top view. Rectangular lamp designs are shown in the figures, differing in the position of the heat dissipation holes. In the design shown in Fig. 1, the heat dissipation holes are located on the side, while in Fig. 2, the holes are positioned on the top. It is important to note that these heat dissipation holes are not straight-through. Their approximate size is 1 mm. Due to the surface tension of water droplets, holes of this size do not allow water to enter the inside of the lamp. Heat dissipation is more efficient when the holes are located on the top, as compared to the side. However, in the presence of water, the heat dissipation holes on the top may become blocked. A disadvantage of square lamps is that an additional reflector must be produced to match the circular light source, leading to increased manufacturing costs.



(a) (b) (c) (d)

Fig. 1. (**a**) Oblique front view, (**b**) oblique rear view, (**c**) side view, and (**d**) top view. Rectangular lamps with heat dissipation holes on side.

(a) (b)

(c) (d)

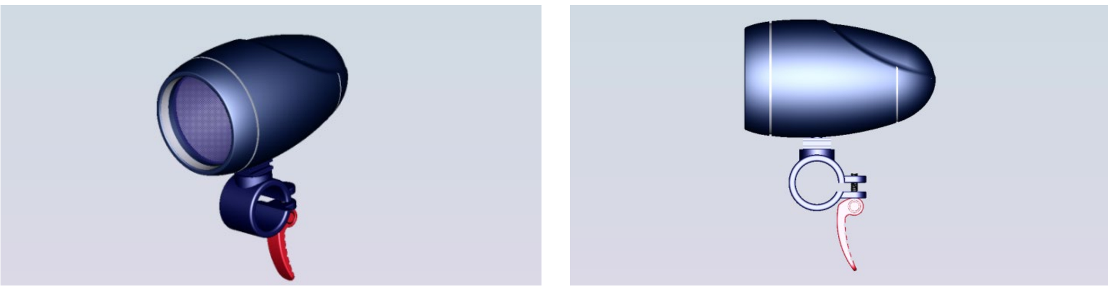
Fig. 2. (**a**) Oblique front view, (**b**) oblique rear view, (**c**) side view, and (**d**) top view. Rectangular lamps with heat dissipation holes on top.

Figs. 3 and 4 show other designs of a circular shape to reduce the cost of producing reflective mirrors to match the light source. Figs. 3(a) and 4(a) show oblique front views, Figs. 3(b) and 4(b) show side views, Figs. 3(c) and 4(c) show rear frontal views, Fig. 3 (d) shows a bottom view, and Fig. 4(d) shows a front frontal view. Figure 3 features a design with heat dissipation holes, whereas the model in Fig. 4 does not have heat dissipation holes and only employs contrasting recessed lines. The base design of the light lamps in Figs. 3 and 4 were modified from the models shown in Figs. 1 and 2 to accommodate the change in the center of gravity with the light source added. The heat dissipation holes in Fig. 3 were located above the circular light lamp. When the bicycle moves, droplets flow along the curvature of the lamp which reduces the accumulation of droplets in the heat dissipation holes and prevents heat dissipation from weakening. The heat dissipation holes of the lamp were placed in the rear part of the model in Fig. 3(c), which was different from that shown in Fig. 4(c). Additionally, the side view in Fig. 3(d) shows the heat dissipation holes above the lamp, while the holes were located on the side in Fig. 4(d).

(**a**) (**b**)

(**c**) (**d**)

Fig. 3. Design of the light lamp in circular shapes using the light source and reducing the cost of producing reflective mirrors. Heat dissipation holes are found in figures. (**a**) oblique front view, (**b**) side view, (**c**) rear frontal view, and (**d**) bottom view.

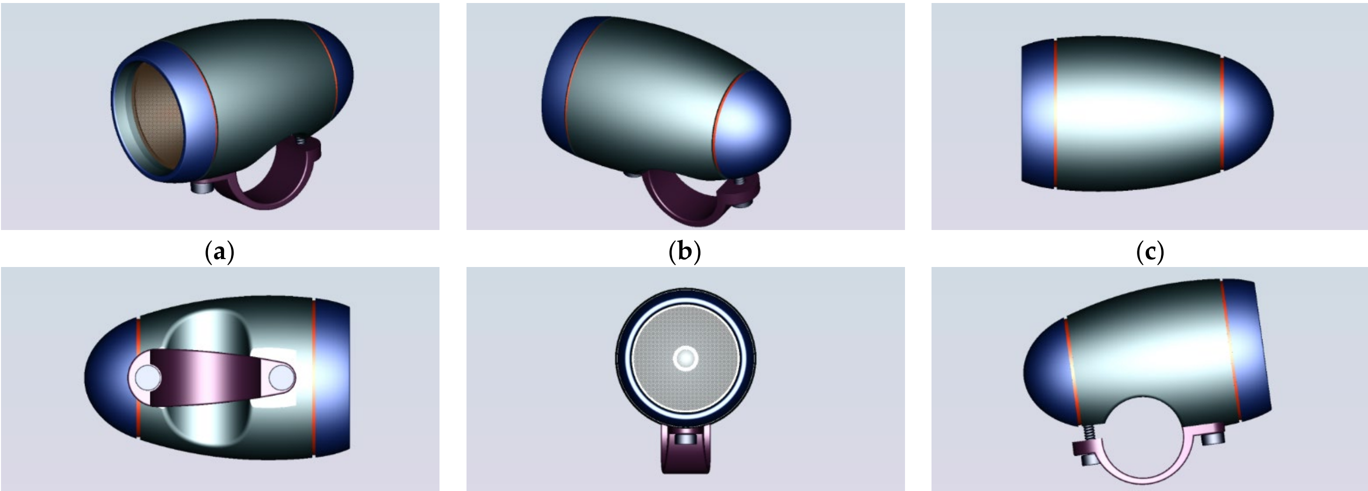


(a) (b)

(c) (d)

Fig. 4. Design of the light lamp in circular shapes using the light source and reducing the cost of producing reflective mirrors. Heat dissipation holes are not found. (**a**) oblique front view, (**b**) side view, (**c**) rear frontal view, and (**d**) frontal view.

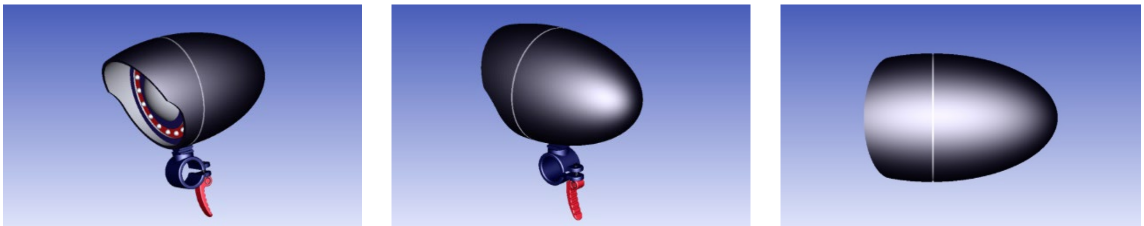
Figs. 5 and 6 depict an egg-shaped light lamp without heat dissipation holes. Figs. 5(a) and 6(a) show oblique front views, Figs. 5(b) and 6(b) display oblique rear views, Figs. 5(c) and 6(c) represent top views, Figs. 5(d) and 6(d) illustrate bottom views, Figs. 5(e) and 6(e) show front views, and Figs. 5(f) and 6(f) present side views. In the model of Fig. 5, the lamp's base was attached with two screws. The advantage of this design was that it reduced the torque applied by vibrations. However, the installation of the two screws was cumbersome. Additionally, due to the light source positioned at the front, space was required, and the bracket design was slightly shifted backward. This moved the center of gravity forward and increased vibration torque. Figure 6 shows a design with a protruding flange at the front. This protruding flange prevented water droplets from entering through the joint between the light source and the lamp, and secondly, it allowed the adjustment of light distribution.



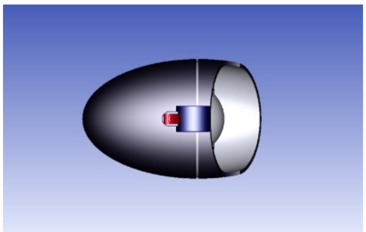
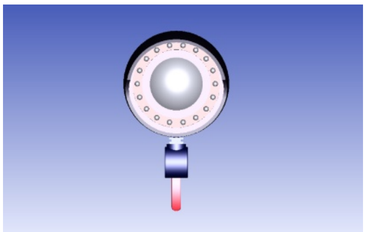
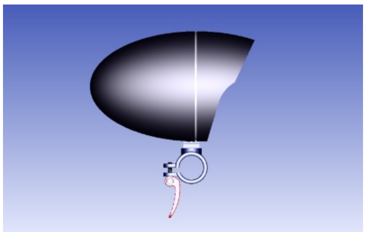
(a) (b) (c)

(d) (e) (f)

Fig. 5. Egg-shaped light lamp attached with screws without heat dissipation holes. (**a**) upper oblique front view, (**b**) upper oblique rear view, (**c**) top view, (**d**) bottom view, (**e**) front view, and (**f**) side view.



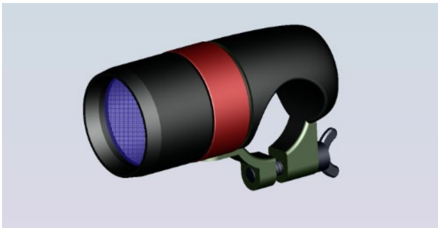
(a) (b) (c)

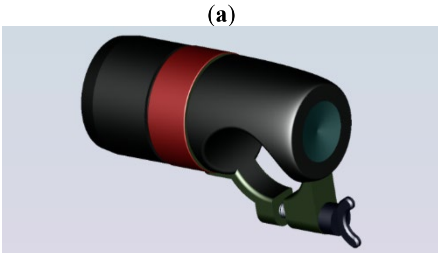
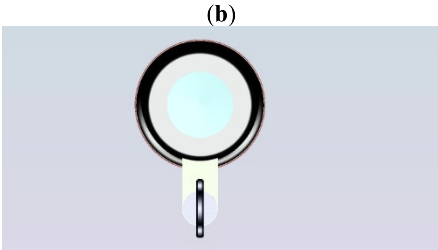
(d) (e) (f)

Fig. 6. Egg-shaped light lamp with protruding flange and no heat dissipation hole. (**a**) upper oblique front view, (**b**) upper oblique rear view, (**c**) top view, (**d**) bottom view, (**e**) front view, and (**f**) side view.

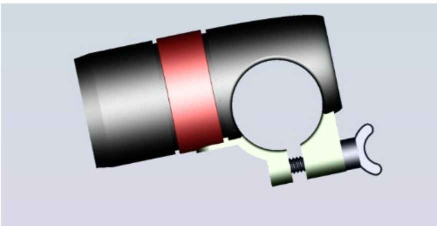
Figure 7 shows the design of a cylindrical shape. Figure 7(a) shows the oblique front view, Fig. 7(b) shows the front frontal view, Fig. 7(c) displays the upper oblique rear view, Fig. 7(d) displays the rear frontal view, and Fig. 7(e) presents the side view. The design features a flat side at the back, which was secured with a single screw for ease of installation and removal. Although this design reduces the cross-sectional area of the windward side, the front end requires sufficient space for installing the light source and circuitry. As a result, the center of gravity was shifted toward the rear side, causing the weight distribution to be biased toward the front. This imbalance, combined with vibrations, exerted sgreater torque and increased the likelihood of loosening or fracturing.




(a) (b)

(c) (d)



(e)

Fig. 7. Design of the light lamp of a cylindrical shape. (**a**) Upper oblique front view, (**b**) front frontal view, (**c**) upper oblique rear view, (**d**) rear frontal view, and (**e**) side view.

4. Discussion

Table 1 displays the specific gravity, shrinkage rate (%), and heat distortion temperature for the six materials tested in this study: BMC, PP, PA, ABS, PC, and PPC. The measurement result of specific gravity showed differences among the six materials. Materials with lower shrinkage rates caused smaller design errors in production. Among them, BMC exhibited expansion and the highest heat resistance temperature. Thus, BMC was suitable for high-power headlights and front fog lamp bulbs and reflectors. However, in this study, pre-assembled LED energy-saving lights were used, so there was no demand for heat resistance. Materials such as PP and ABS with low heat distortion temperatures could also be used for headlights and front fog lamps. However, these materials deform when exposed to external heat sources such as boiling water during camping. Therefore, it is not recommended to use these two materials for light fixtures.

Table 1. Specific gravity, shrinkage rate (%), and heat distortion temperature of BMC, PP, PA, ABS, PC, and PPC.

Materials	Specific gravity	Shrinkage Rate (%)	Heat Distortion Temperature (°C)
BMC	1.6	−0.08	>200
PP	1.04	1.2	80
PA	1.23	0.6~0.8	155
ABS	1.04	0.5	93
PC	1.2	0.5~0.7	125
PPC	1.2	0.8~1.0	149

Fig. 8 presents a comparison of market prices (per kg) for six different materials. The prices of the materials were in the order of BMC, PP, PA, ABS, PC, and PPC. BMC, PP, and PA showed fewer price differences. For secondary processing considerations, it is advisable to choose plastics with better vacuum coating effects for improved appearance and adhesion. However, the actual application also requires considerations of mold structure and product formability. Future research is necessary to further investigate light patterns, light distribution values, waterproofing, adhesion properties of wires and switches, structural testing of brackets, and selection of power supply methods.

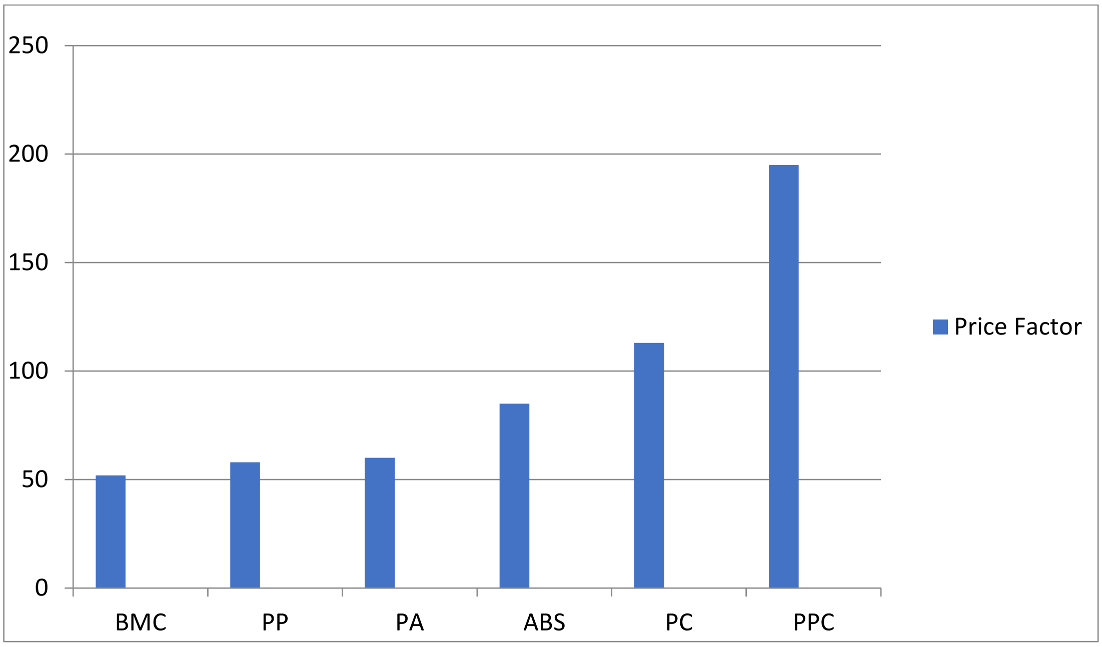


Fig. 8. Market prices of BMC, PP, PA, ABS, PC, and PPC per kilogram.

5. Conclusions

We designed seven different heat dissipation lamps and compared six materials (BMC, PP, PA, ABS, PC, and PPC) for the lamps. The result provided options to choose appropriate materials and designs for bicycle headlights using commercially available LED lights. In the selection of appropriate materials for the lamp, several factors need to be considered. First, inexpensive plastic is preferred. Secondly, plastics with higher heat resistance are recommended. Additionally, materials with stable dimensions, characterized by low molding shrinkage and secondary shrinkage rates are required. Lastly, plastics with superior vacuum deposition effects are adequate as it allows attractive appearances and excellent adhesion. When choosing the lamp design, heat dissipation, easy assembly and disassembly, and reducing air resistance in the frontal area must be taken into account. Lastly, a design with minimal vibration torque is necessary.

Author Contributions: conceptualization, S.C. Hung, D. Yang, and Y.C. Hsu; methodology, S.C. Hung, D. Yang, and Y.C. Hsu; validation, S.C. Hung, D. Yang, and Y.C. Hsu; investigation, S.C. Hung, D. Yang, and Y.C. Hsu; data curation, S.C. Hung, D. Yang, and Y.C. Hsu; writing—original draft preparation, S.C. Hung, D. Yang, and Y.C. Hsu; writing—review and editing, S.C. Hung, D. Yang and Y.C. Hsu; visualization, S.C. Hung, D. Yang, and Y.C. Hsu. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

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