Material and Process Analysis

Design for Manufacture

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BM786

BRYMEN
BRIGHT PEOPLE'S CHOICE

The Brymen BM786, branded with signature EEVBlog blue, is a high-quality multimeter for electrical and electronics testing and design. It retails at USD$154 in 2023.

Criteria of Physical Features

- Rugged and drop proof construction
- Meets UL Listed electrical safety standards
- CAT III 1kV, CAT IV 600V (8kV transient)
- Ergonomic textured grip for secure handling

Sustainability

Materials used in the BM786 include PC, TPE, silicone, and PP which are non-renewable but are recyclable. However, the overmoulded PC and TPE are difficult to separate, making it unviable for typical recycling programs. Low levels of phthalate plasticizers are added to TPE to improve flexibility and can be harmful to human health. Most silicones are non-toxic, though recycling programs for silicone are uncommon. Unlike PC, PP does not use the bisphenol A precursor which is a human hormone disruptor.

Design Summary

Pros	Cons
+ Minimal assembly due to screen cover, chassis, and overmoulding being the same part.	- Integration of screen cover/chassis means it cannot be individually replaced when scratched or broken.
+ Knit lines hidden by texture and detailed design around buttons.	- Overmoulding means the chassis cannot be easily recycled due to inseparable different materials.
+ Overmoulding improves appearance, grip, protection, thermal/electrical insulation	- PC screen cover scratches easily

Made in Taiwan

Material Properties

PC
Polycarbonate

PC is a thermoplastic polymer with carbonate groups resulting ***high strength and toughness***. It is used for the clear screen cover, range switch, and body.

+ Excellent impact resistance
+ Excellent electrical insulation properties
+ Can be optically transparent
+ High temperature capability, can be flame-retardant
- Susceptible to scratches and long-term UV damage

SI
Silicone

Silicone is an elastomer with stable ***rubber-like*** properties used as heat cured rubber for buttons.

+ Good electrical insulation properties
+ Flexible at low temperatures
+ Low chemical reactivity
+ Abrasion resistance
+ Easy to pigment in a variety of colours
- High cost, may need fillers to reduce cost

TPE
Thermoplastic Elastomer

TPE is a family of copolymers with ***rubber-like*** physical properties due to their composition of crystalline and amorphous domains.

+ High friction grip
+ Resistance to drops and abrasion
+ Good electrical insulation properties
+ Good chemical resistance to alcohols, acids, bases
- High cost compared to other resins

PP
Polypropylene

PP is a common thermoplastic polymer used in both homopolymer or copolymer forms for better strength or impact resistance respectively. The ***homopolymer PP is used*** for the binding posts where the multimeter probes connect.

+ Excellent electrical insulation
+ Good toughness and fatigue resistance
- Oxidative degradation with contact to some metals
- Poor UV resistance

BM786

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Process Analysis

The transparent PC is keyed into the PC chassis, suggesting the ***screen cover is injection moulded first***, then placed into the cavity where the chassis is injected.

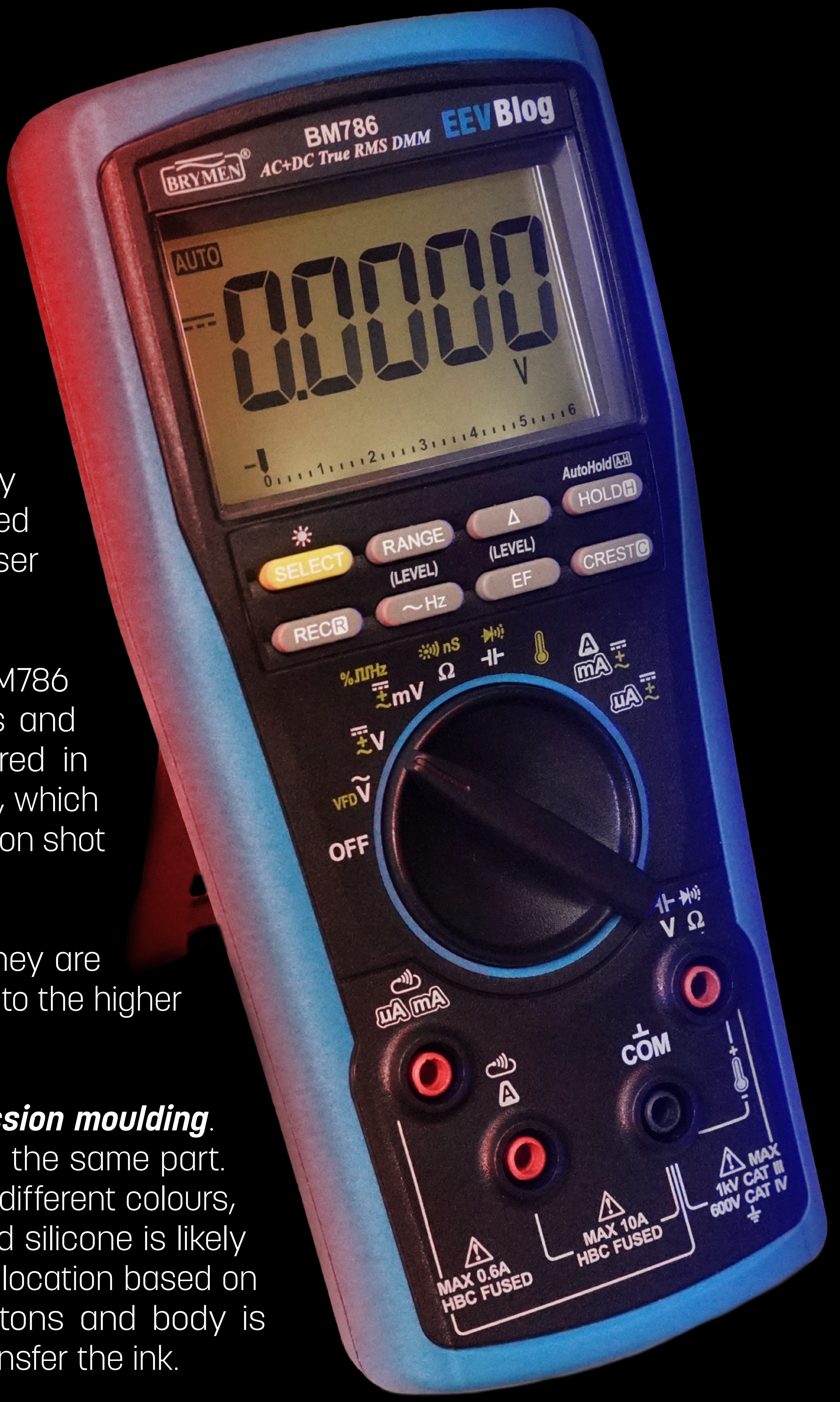
The PC chassis is ***overmoulded*** with TPE which is clearly visible upon disassembly where the two materials are keyed together for improved adhesion. The black PC has a courser ***sandblasted texture*** on the mould compared to the TPE.

Due to the nature of high-end test equipment the Brymen BM786 is a ***low quantity,*** but ***high quality*** product. The chassis and overmoulding tool are therefore most likely manufactured in ***two-cavity*** tools. This allows both the front and back halves, which require a similar resin volume, to be made in the same injection shot to ensure ***consistent material colour between halves***.

The PP binding posts have a visible part line, indicating they are also injection moulded. A ***multi-cavity*** tool is likely used due to the higher quantity of binding posts in other Brymen products.

The single-part silicone buttons are made using ***compression moulding***. This is apparent due to multi-colour yellow/grey silicone in the same part. This button mould is ***reused on other Brymen products*** with different colours, hence it is likely ***multi-cavity***. This also means the coloured silicone is likely placed manually into the compression mould in the correct location based on the multimeter being produced. The legend on the buttons and body is achieved with ***pad-printing,*** using a silicone substrate to transfer the ink.

Made in Taiwan



Production Economics

Labour Cost

The relatively low volume production of the BM786 results in many factors which increase the labour cost. These include many manual operations in the injection moulding process such as ***hand loading*** the screen cover and the chassis into each overmoulding stage. The compression moulding of the silicone buttons also requires hand placement of coloured resin into specific button locations, given the use of this part in other models of multimeter.

Manual assembly is required given the complexity of internal sub-assemblies such as the printed circuit board with its mounting screws and range switch. Along with the four self-tapping screws for the chassis this results in a relatively high part of the production cost being labour related, necessary for this quality and quantity.

Tooling Cost

The overmoulding requires two stages of tooling, along with the tools required for the binding posts, screen cover, buttons, and range switch. Most ***parts are reused for other models*** to amortise the tooling cost. The overmoulding tools are unlikely to be part of an automated die changer with double injection barrels given the size of the required two cavities for front and back halves. This also saves on tooling cost, ***manual placement*** of parts into each overmould stage may be ***more cost effective at low volumes***.

Material Grade and Cost

The use of TPE and PC for the main chassis increases cost when compared to more typical and cheaper resins such as ABS. However, the benefits of these resins for this application outweighs the cost. At the time of production in 2021 the regional market prices were ***USD$3/kg for PC*** and ***USD$2.6/kg for TPE***. This depends on the grade of each material, such as the ***specific TPE chosen for sufficient bond strength to PC*** as an overmould. The buttons have a low mould volume but a high cost per weight of ***USD$5.7/kg*** for silicone, while the bindings posts use ***PP at USD$1.5/kg***.

MX Master 3 logitech

The Logitech MX Master 3 is a versatile mouse suitable for professional and everyday use retailing around USD$100. The distinct combination of the ergonomic yet attractive shape, horizontal scroll wheel, high precision sensor, and electromagnetic scrolling mechanism result in high desirability across many applications.

Criteria of Physical Features

- Ergonomic design to prevent strain for extended use
- Human compatible material for comfort and longevity
- Low friction motion for precise control across a variety of surfaces
- Consideration of material density to achieve desired balance & weight
- Wear resistance and adequate strength for highly repetitive actions
- Non-conductive materials to allow wireless signal transmission

Design Summary

Pros	Cons
+ Comfortable and ergonomic TPE grip	- TPE reduces the service life given its degradation from hand oils
+ Strong and rigid chassis	- Grip ergonomics may not be suitable for users with smaller hands
+ TPE part line is barely visible and cannot be felt on hand in normal use	- ABS plastic may wear over time becoming shiny in high traffic areas such as the left and right click
+ Use of PTFE feet allow repeatable low friction movements across many types of surfaces	- Use of metals and heavy overmoulded parts increase weight, potentially causing fatigue faster when moving quickly.
+ Plated steel scroll wheels give a premium user experience.	- Nickel plating may pose allergen risk
+ Excellent texture and colour matching between different plastics	

Made in China

Material Properties

PM
Powdered Metal (Steel)

Fine steel (iron and carbon alloy) powder is ***pressed and sintered*** followed by secondary machining for knurling as well as ***nickel plating*** apparent due to the lustre and warm tone compared to chroming.

+ Plating improves finish and rust/wear resistance
+ Magnetic properties for unique scroll mechanism
+ Reduced cost by using cheaper steel with plating
- Skin allergies to nickel plating on high touch area

TPE
Thermoplastic Elastomer

TPE is a family of copolymers with ***rubber-like*** physical properties due to their composition of crystalline and amorphous domains.

+ High friction comfortable grip
+ Chemical and abrasion resistance for handling
+ Flexibility allows for hidden thumb rest button
- High cost compared to other resins
- Reaction with hand oils eventually degrades TPE

ABS
Acrylonitrile Butadiene Styrene

ABS is one of the ***most widely used thermoplastics***. Acrylonitrile for chemical and heat stability, Butadiene for toughness and impact strength, Styrene for rigidity and processability.

+ Can achieve bright surface finish
+ Cheap resin available in many grades
+ Good impact/strain resistance and toughness
- Scratches easily, wears over time to shiny finish

PTFE
Polytetrafluoro-ethylene

PTFE is a thermoplastic fluorocarbon based on polyethylene and is used as pads on the bottom of the mouse for ***smooth and predictable movement.***

+ Extremely low coefficient of friction and non-stick
+ Highly wear resistant
- Health risks if manufactured with perfluorooctanoic acid, or when heated beyond 260°C

MX Master 3 logitech

Process Analysis

The ***TPE is overmoulded to an ABS under body*** which is only visible upon disassembly where the two plastics are keyed together in the moulding operation for best adhesion. Overmoulding is likely achieved using a ***two-barrel injection moulding machine*** with two stages of cavity. One side of the die rotates between first injecting the ABS followed by the TPE. The thumb rest portion of the mouse is entirely TPE to allow flexure for the integrated thumb button. The ABS part of the overmoulding only requires two mould sides, but the TPE mould has a much more complex structure with undercuts that are achieved with two side cores. It is likely the ***overmoulding die only contains two cavities***, one for each ABS and TPE stage, both due to its complexity and to keep the die small enough to fit the rotating assembly of the injection moulding machine.

The bottom half of the MX Master 3 is then injection moulded in a separate tool, which also utilises a ***sliding core*** to achieve the undercut present in the ABS near the side scroll wheel. This can be identified by the part line around this area which is separate from the main part line around the base. All the other ABS buttons on the mouse may be made in their own ***multi-cavity tool*** given their forms do not require any side actions. This also improves the colour matching and reduces tool count. These tools, and the more complex bottom half tool are likely ***single-cavity***, this helps match the production speed of the overmoulded top part.

The two plated steel pieces are most likely ***powdered metal*** given their compatible aspect ratio, high production volume, and the presence of a textured finish on the side scroll wheel which would not be possible with lathe knurling alone. After hydraulic pressing the powdered steel parts would be sintered in an oven before ***secondary lathing*** to clean up the parts with chamfers and to achieve the shiny finish in some areas. The knurling on the main scroll wheel is rolled or cut by lathe given its sharper edges whereas the side scroll wheel has texture, likely from the powdered metal process. Steel is used for the main scroll wheel as the ***scroll mechanism relies on the material's magnetic properties to function***. These steel parts are plated to give a finish with a warm lustre, indicating the use of ***nickel plating*** rather than chrome plating which has a cooler tone when finished.

Made in China

Production Economics

Labour Cost

While the use of overmoulding increases tooling complexity, it results in ***lower assembly time*** and therefore reduces labour cost. Some elements of the mouse may be assembled robotically, but the ***final assembly is likely by hand*** given the complexity and difficulty manipulating smaller parts. This increases the overall cost of the product but is feasible given the premium price point of the MX Master 3.

The multi-cavity button tool may require removal of runners at the gate of each part if not removed automatically by the tool.

Tooling Cost

The two-shot overmoulding process with side action cores significantly increases tooling cost and is reflected in the premium market position. However, the overmoulding is required to meet the expectations of user experience and ergonomics at this price. The overall ***tooling cost is amortised by the high volume*** of this product.

Material Grade and Cost

The ABS used under the TPE overmoulding is not externally visible, making it less critical for colour matching which may reduce cost. At the time of manufacture in 2021 the market prices in China were around ***USD$2.4/kg for ABS***, ***USD$2.6/kg for TPE***, ***USD$8.5/kg for PTFE***, and ***USD$5/kg for steel alloys***. This steel pricing may not accurately reflect the cost of the material when prepared for the powdered metal process.

Sustainability

Logitech claims that this colour of MX Master 3 mouse uses up to ***27% post-consumer recycled plastic***, resulting in an ***avoidance of 10.6 tonnes of CO_2 emissions per 100,000 units***. This post-consumer recycled plastic is likely the ABS used in the structural component of the overmoulding that is not externally visible and so can vary in colour and composition without detriment to the product's appearance.

Camry Mirror

SMR TOYOTA

Some of Toyota's highest volume vehicles in Australia, the 2011-2017 Camry, and 2012-2017 Aurion were fitted with these side mirrors. With styling by Toyota, the mirror and bracket were designed and manufactured by SMR Automotive in South Australia. The mirror contains a manual detent folding mechanism, electric mirror angle adjustment, rear projecting indicator, and blind spot indicator behind the mirror glass. This mirror represents best in class performance at the time of manufacture, with the highest vibration performance rating of all other global suppliers for Toyota. The total cost to manufacture was around AUD$30 in 2011.

Criteria of Physical Features

- Minimise wind noise and vehicle associated vibrations
- Optically clear indicator lens with precise projection
- Pass associated Australian and EU certifications such as pedestrian injury testing to determine appropriate use of safe radii and form
- Reliability of folding across temperature range
- Low aerodynamic drag

Design Summary

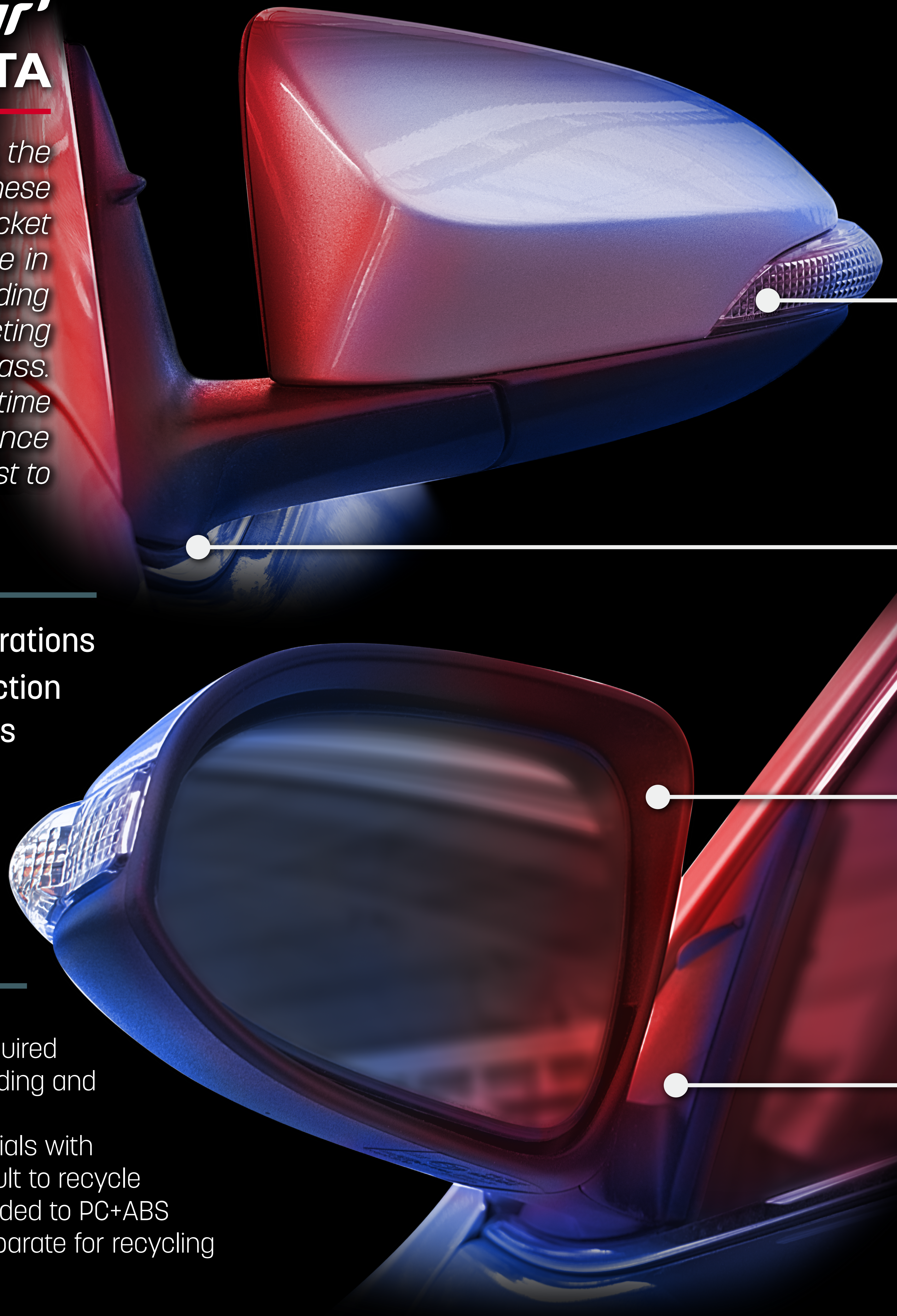
Pros

+ Excellent wind/vibration handling
+ Use of compliant LDPE gasket for sealing surface against water
+ Effective use of appearance plastics as structural parts to reduce part count.
+ Case overhang prevents dew formation on mirror glass

Cons

- More UV stabilisers required in PA part to reduce fading and degradation over time
- Composites and materials with additives can be difficult to recycle
- PMMA lens friction welded to PC+ABS backing, difficult to separate for recycling

Made in South Australia



Material Properties

PMMA *Polymethyl methacrylate*

PMMA, also known as acrylic, is used for the indicator lens. Acrylic is a thermoplastic typically used as a ***substitute for glass***.

+ Excellent light transmittance for effective lensing
+ High resistance to UV light weathering
+ Good scratch resistance compared to PC
- Less scratch resistance compared to glass
- Poor impact resistance

LDPE *Low Density Polyethylene*

LDPE is used for the gasket which sits between the mirror bracket and the car to ***reduce wind noise and prevent water ingress***.

+ Low water absorption
+ Felxibility sufficient for a gasket to fit a surface
+ Good processability
- Poor UV resistance without the use of stablisers

ASA *Acrylonitrile Styrene Acrylate*

ASA is an ABS alternative that ***improves on weather resistance***, and is used for the case of the mirror.

+ High impact resistance
+ Excellent UV weathering resistance, retains colour
+ Good thermal stability
- Mildly hygroscopic, needs low humidity processing

PA *Polyamide Long Glass Fibre*

Long Glass Fibre Filled PA (50%) is a thermoplastic composite used for the mirror bracket. The fibres are visibly aligned in the material flow direction during moulding creating ***anisotropic tensile behaviour***.

+ Longer fibres decrease warp when moulded
+ High tensile and fatigue strength
+ Low dimensional creep under static loads
+ High impact resistance
- Glass fill causes increased abrasion and tool wear

Camry Mirror

Process Analysis

All tools contain two cavities, one for each left and right. Injection occurs through a ***two-way manifold hot runner valve gate*** to both cavities. This ensures identical flow patterns without the need for runners within the tool which increases cycle time and wastes resin.

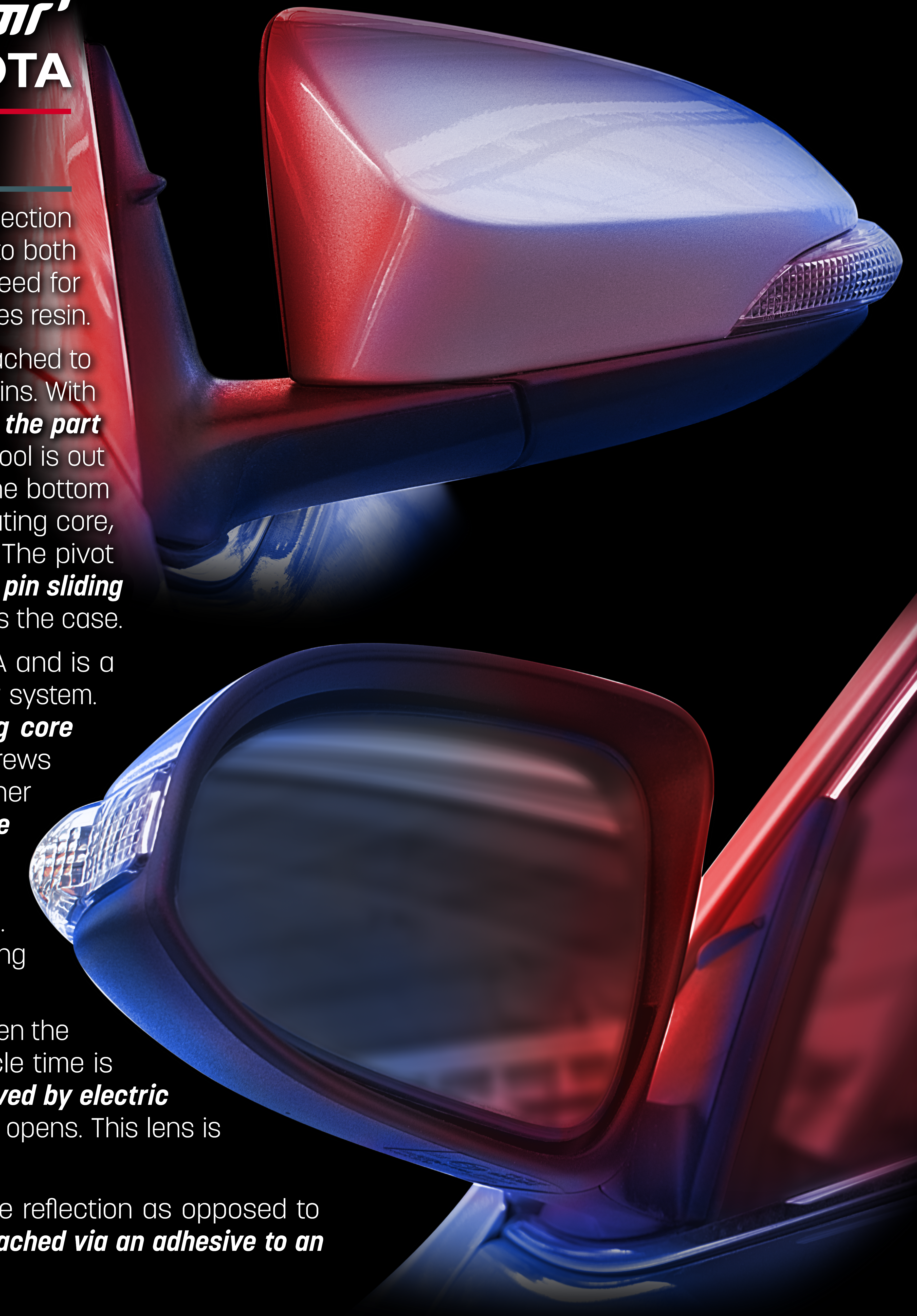
The ASA mirror case is ejected from the moving half still attached to the undercut part of the tool which moves with the ejector pins. With this undercut section holding the part, a ***robotic arm grips the part and rotates it out of the undercut*** now that the rest of the tool is out of the way. This undercut is untextured and is visible in the bottom corner behind the mirror glass. This is the inverse of a rotating core, where the part is rotated rather than an area of the tool. The pivot detents for folding and locating are achieved with an ***angled pin sliding core***. The gate is located where the painted ABS scalp covers the case.

The mirror bracket made of 50% long glass fibre filled PA and is a complex tool, requiring two sliding cores and an angled lifter system. The ***underside of the bracket uses an angled pin sliding core*** against the shut-face to achieve the undercut for the screws which hold the pivot mechanism. This is covered by another ASA part with matching texture. ***Different texture depths were used on the adjacent ASA and PA parts to match their appearance***. The pivot mechanism of the bracket was formed with a ***hydraulically actuated internal sliding core***. Sink marks from the bracket bosses were eliminated by using angled lifters to remove material thickness under each boss.

The PMMA indicator lens uses ***runners with an edge gate*** given the small volume of the part for the two-cavity mould so cycle time is already lower than other parts. The ***runner system is removed by electric cutters*** which are positioned by a robotic arm once the tool opens. This lens is ***friction welded*** to the PC+ABS backing that hold the lamp.

First surface mirror glass is used, improving clarity of the reflection as opposed to placing the mirror finish behind glass. This glass is then ***attached via an adhesive to an injection moulded PP backing plate***.

Made in South Australia



Production Economics

Labour Cost

Around ***40,000 pairs of mirrors were manufactured per year***, making the speed and reliability of the labour process critical. Assembly was ***completed largely by production jigs***, combining parts under known orientations and forces. The use of ***semi-automated jigs decreased handling time*** and manual labour required from assembly workers. The screws for the hinge mechanism were installed using electric drivers, reducing strain on the operators and producing repeatable torque. The hinge ***lubricant was dispensed by the jig for high repeatability***. Labour makes up around 30% of the mirrors cost.

Tooling Cost

The ***approximate total tooling cost was AUD$1 million*** in 2011. Using appearance plastics as structural elements of the design ***increases tool complexity and cost but reduces the number of parts required***. The use of a robotically assisted injection moulding cycle increases the tooling cost, but greatly decreasing manual processing. The cost of assembly jigs is outweighed by associated savings in labour cost.

Material Grade and Cost

The ABS used for the scalp is a ***specific grade to achieve good adhesion during the painting process***. The PA grade was selected given Toyota's preference from prior usage in mirror applications. A ***PA with higher UV stabiliser content should have been used***, as the mirror bracket becomes faded within a few years of sun exposure. The composite long glass fibre filled PA was the most costly material, followed by ASA for around AUD$5.4/kg at the time of manufacture.

Sustainability

Each part of the mirror assembly has ***material codes for recyclability***. Wasted runner plastic is avoided for all parts using the hot runner system, which only excludes the PMMA lens. ***While waste plastic from injection moulding is recycled it requires more energy to do so***. Most parts of the assembly are separable allowing for deconstruction of recyclable components. The composites and special material grades are not easily recycled although they help to increase the service life of the mirror, preventing it from becoming waste. The only use of adhesives is in the mirror glass to avoid shattering and becoming a hazard. ***LDPE was chosen as a recyclable alternative to rubbers for the gasket***. The ***Altair OptiStruct*** program was used to optimise the volume to strength ratio of structural components, saving critical material and cost, reducing resin usage.

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