Abstract – Plastics are the choice materials in the automotive industry to meet the challenges towards low cost and high performance. Applications of plastics components in the automotive industry have been increasing over the last decades to reduce car weight and manufacturing cost. In this paper, studies have been conducted on polymer over moulding and in-mould painting applications for the automotive industry. Over moulded specimens and in-mould painted samples for automotive applications have been successfully manufactured. Preliminary capabilities on over moulding and in-mould painting have also been developed in SIMTech. In-mould painting plastics resins have been successfully used in in-mould painting trials. Experimental results on the bonding between the components of the over moulded parts show that the bonding performance can be affected by many factors such as the combination of materials, process conditions, and sample pre-treatment. Plasma treatment can also significantly enhance the bonding performance.

Keywords: Plastics, Over moulding, Automotive, In-mould painting, Bonding

1 BACKGROUND

Polymers have been used in the automotive industry since the early part of the 20th century but the ongoing development of advanced, high-performance polymers has dramatically increased their usage in both the amount of materials used and types of the components they have been used for [1].

Weight reduction has always been a key focus in the automotive industry. Cars with more polymer usage are light and therefore are of lower fuel consumption and carbon dioxide emission. It is estimated that every 10% reduction in vehicle weight results in 5% to 7% fuel saving [2]. This means that for every kilogram of weight reduction in a vehicle, there is about 20 kg of carbon dioxide reduction [3]. Fuel efficiency is not only a demand from customers but also a major concern of governments all over the world. For example, the European Union (EU) has setup the goal of achieving an average carbon dioxide emission figure of 120 g/km for all passenger cars marketed in the Union by 2010. It would be very challenging for the industry to meet the objective by just downsizing the car. The incorporation of lightweight materials in automobiles is a necessity [4].

According to an annual survey conducted by DuPont Automotive, materials that reduce weight and cost while providing better durability and physical properties continue to top the wish list of automotive engineers [5]. Applications of polymer materials will play an even more important role in the development of the cars of tomorrow.

Polymeric materials are about six times lighter than steel, they are rust resistant, and can be manufactured into components of complicated geometry shapes with low costs through highly automated processes such as the injection moulding and extrusion technologies. The advantages of polymer materials provide tremendous flexibilities and freedom for stylish designs, which have shown increasing importance as a distinctive feature and basis for purchasing decisions.

The automotive industry has incorporated plastics in a variety of applications; they form the interior components of most cars, for example, as well as bumper covers and fenders. Polymeric composites (plastics reinforced with either glass or carbon fibres) have also been used in the bodies of racing cars and some commercially produced vehicles. A full range of plastics processing technologies, injection, extrusion, thermoforming, calendering, rotational moulding, compression and expansion have been developed for manufacturing of various automotive components. Many types of polymers have been used in the automobile industry and the amount of usage has also increased for the same model of cars but manufactured in different years as illustrated in Fig. 1 [6].

Polymers have already been widely used in the automotive industry. To further increase the applications, new materials and process technologies must be developed to promote further applications. Polymer glazing applications and polymer elastomer for sealing systems are some of the areas with great potentials for further improvement. On the other hand, new polymer process technologies are also being developed to produce components with higher quality to suit more stringent applications.

In this project some of the new applications and process technologies are studied and identified as potential areas for future capability development.

2 OBJECTIVE

The automotive industry today is a mature and very competitive industry. Products with high performance, high fuel efficiency, low cost, and stylish...
design are some of the factors that attract customers. Applications of over moulded plastics components can meet many of the demands in the automotive industry as the properties of different polymers can be better utilised and many modern design features can be easily implemented. The objective of this study is to develop over moulding process technologies and capabilities for multi-component plastic automotive product applications.

3 METHODOLOGY

In this project, polymer materials for automotive applications have been studied. Investigations have been carried out on industrial application development of polymeric materials for the automotive industry. Studies on manufacturing processes for automotive plastics components have also been conducted, especially for the over moulding process, as it is widely used in the automotive components manufacturing process. In-mould painting materials and moulding technologies have been studied and samples were prepared for testing and characterisation.

3.1 Over Moulding Process Technology and Capability Development

Injection moulding is the most important of all the commercial methods of plastics processing. Many variations have been developed and one of the rapidly expanding fields is multi-material injection moulding [7], or over moulding technologies.

Over moulding is the injection moulding process where one material is moulded onto a second material to form hybrid structure components as illustrated in Fig. 2. Plastics, elastomers, metals, ceramics, fabrics can be used in the process. Each material can be used at the optimal level to provide specific property enhancements. This is particularly important where processors are looking to gain technological advantages over rivals by adding value to their products. In such processes, two or more types of materials are used for manufacturing of components to better utilise the properties of the materials. Whilst tooling costs can be higher, cost savings can be made by eliminating assembly steps.

There are many advantages to use components consisting of more than two materials. First of all, it can enhance features of product designs in the following aspects:

- **Safety**
  - Improved grip in dry and wet environments
  - Vibration damping
- **Ergonomics**
  - Increase in comfort level
- **Product Functionality**
  - Water resistant seal
  - Sound absorption
  - Electrical insulation

Secondly, multi-material processes can add value to customers. Listed below are some of the quality aspects that can be improved through multi-component applications:

- Colour/appearance
- UV protection
- Soft-touch
- Product differentiation
- Localised performance (clarity, heat, stiffness)
- Weight reduction
- Assembly efficiency
- Customers benefit
- Eliminating assembly operations, decreased number of parts, enhanced product quality, and increased design flexibility

Fig. 1. Types of plastics used in the same brand of cars (Passat 1997 and Passat 2005) have increased over the years.

Fig. 2. The over moulding process using two injection barrels.

Applications of over moulding technologies have been increasing rapidly in recent years, due to the development of new thermoplastics elastomer (TPE) materials and invention of new process technologies. Multi-material moulding has been more widely used in Europe than in the US [8].
The over moulding processes can be further classified into the following processes or applications:

- **Co-injection Moulding**
  - Requires a special injection moulding machine with two or more barrels
  - Allowing two or more materials to shot into the same mould

- **Insert Moulding**
  - The most widely used process
  - A pre-moulded insert is placed into a mould and the second material is shot directly over it
  - Conventional machines can be used
  - Tooling costs are lower than multi-shot processing

- **Multiple Material Moulding**
  - Also known as two-shot or multi-shot moulding
  - Using two separate mould cavities
  - Mould one material over another to create a special effect

- **In-mould Decoration**
  - A pre-decorated film is place in cavity
  - Melt is over moulded onto the film to form decorated surface

Generally, insert moulding is the process of choice when annual production volumes and local labour costs are low. For higher volume production programs (over 250,000 units annually) or in places of high labour costs, multi-shot moulding operations are the method of choice, while co-injection moulding is usually used for sandwich structure moulding.

In this project, the over moulding technologies are used for the manufacture of selected automotive components, and capabilities have been developed in over moulding of multi-components, as well as in-mould painting of plastics components by using polymer based paints as one component. Both the co-injection moulding and the multi-shot moulding process were employed for automotive components manufacturing.

The co-injection moulding studies were carried out using a Battenfeld dual barrel injection moulding machine. The two injection barrels allow two different materials to be introduced into the same mould. The process comprises sequential and/or concurrent injection of a “skin” material and a “core” material into a cavity, as shown in Fig. 3. It offers the inherent flexibility of using each material at its optimum to reduce the material cost, injection pressure, clamping tonnage, and residual stresses.

The benefits of co-injection moulding are the reduced overall production time, superior part quality, and lower labour requirements. Common usage is in decorating aesthetic plastic parts such as PC keyboard and keycaps or to mould together two dissimilar materials such as nylon and thermoplastic elastomer.

Moulding experiment studies were also carried out for manufacturing of two-component plastics components through two shot moulding process. In the two shot moulding process, an injection mould with two injection mould cavities are developed with the first one being used for the first component moulding. The moulded part is then transferred to the second cavity for injection of the second material to form a two-component part.

![Fig. 3. A dual-barrel injection system for co-injection moulding process.](image)

### 3.2 Applications of Polymer-based Colorant for In-mould Painting Application

Many advantages are gained in the product by combining different properties. For example, recycle can be used as a core material with a virgin resin skin. In the automotive industry, painting of the car body is an expensive and environmentally unfriendly process. The over moulding processes make it possible to produce plastics components with coloured polymer resins and eliminate the downstream painting process.

In order to produce components with painted surface quality, studies were conducted to search and select coloured resins suitable for automotive applications. One such resin available in the market is DuPontTM Surlyn® superfloss moulding alloy, which is ideal for applications that require a high gloss, moulded-in-colour surface finish directly from the mould. The material is weather-able, durable and provides good scratch and abrasion resistance. It therefore offers an excellent, lower cost, more environmentally friendly alternative to painting. In this study, the DuPont coloured resin is used in the two-shot moulding experiments to produce parts with desired colour and finish.

### 3.3 Bonding Performance Studies for Over Moulded Plastics Components

Although over moulding provide many advantages, there are also potential problems. Compatibility is important for interfacial adhesion. Different materials have varying rheological properties and optimal moulding conditions, which can limit material choice. This area offers vast opportunity for research as there have been few studies on co-moulding incompatible polymers.
Bonding between different components in over moulded parts can be a challenging issue especially in the two-shot moulding process where the second melt is injected into the mould cavity after the first component is already solidified. To achieve good bonding, the material combination needs to be selected carefully. For example, when selecting a thermoplastics elastomer (TPE) for an over moulding application, the substrate type should be considered. Not all TPEs will bond to all types of substrates; for example, a TPE that bonds to polypropylene (PP) will not adhere very well to polycarbonate (PC). In this project, the bonding performance was investigated for over moulded components under different process conditions. The effects of plasma treatment were also studied for over moulded components.

4 RESULTS & DISCUSSION

In this project the co-injection moulding process was employed to mould vehicle components with the outer layer being a coloured resin with good surface finish and resistance. This serves to produce multi-shot and in-mould painted components with improved surface performance for body panel and window applications.

Compared with plastics parts fabricated through moulding and then painting process, this method has many advantages. The finished components are ready to use with no further process needed. It also eliminates the need for downstream painting process, which is costly and environmentally unfriendly. Figure 4 shows a plastics vehicle part moulded using the co-injection moulding process. The surface layer used was a coloured polymer resin with good weatherability for automotive applications.

In the co-injection moulding process, control of the surface layer thickness is a very important issue. The surface layer should spread uniformly and encompass the whole component. As the resins used for surface layers are usually more expensive, it is therefore desired that a thin layer sufficient to protect the part be applied. The distribution of the thickness of the moulded layers is very much affected by the viscosity of the two polymer resins used in the process.

As shown in Fig. 5, the viscosity ratio of the two polymer melt is the key factor to control. In the process, the skin material is usually injected into the mould first, followed by the core component. If the viscosity of the core material is much higher than the skin material, the core material is difficult to flow forward, and will tend to expand sideways, resulting in a thin skin layer. On the other hand, if the viscosity of the core materials is much lower than the skin material, the core melt will tend to move forward as there is less resistance in the forwarding direction, resulting a thick skin layer. The combination of the skin and core materials needs to be carefully selected to achieve the desired results.

![Fig. 4. An in mould painted vehicle component manufactured by the co-injection moulding process.](image)

![Fig. 5. The viscosity ratio of core vs. skin materials (core / skin) plays an important role in determining the thickness uniformity and length of core penetration.](image)
In order to develop full capabilities of multi-component moulding for automotive components applications, moulding experiment studies were also carried out for manufacturing of two-component plastics components through two shot moulding process.

The injection moulding machine used was a 100 tonne Netstal moulding machine, and the two mould cavities were manufactured on the same mould base. Figure 7 shows some of the two-shot moulded samples produced in this project using different polymer resin combinations.

Fig. 6. The injection moulded window screen using two transparent polymer resins through co-injection moulding process.

Fig. 7. Electrical resistivity of PBT carbon nanotube composites measured along the longitudinal direction and the loop directions for the tube samples.

In this project, bonding performance studies were carried out for different polymer materials combinations: PP, ABS, and PC resins with the DuPont in-mould painting resin DuPontTM Surlyn®. Plasma treatment effects were also studied for the polymer resin combinations.

It can be seen from Fig. 8(a) that without plasma treatment, the bonding strength between the in-mould painting resin and the ABS resin was poor, and can be peeled off without applying very high strength. Plasma treatment, on the other hand, can greatly improve the bonding performance for the same material combinations, as shown in Fig. 8(b).

Fig. 8(a). Over moulded part of poor bonding performance without plasma treatment.

Fig. 8(b). Over moulded two-shot moulding part with improved bonding performance after plasma treatment.

5 CONCLUSION

Studies have been conducted herein on the applications of polymer materials in the automotive industry. Plastics are the choice materials in the automotive industry to meet the challenges towards low cost and high performance. Polymeric materials provide greater freedom of design as they can be formed to complicated shapes through many process methods.

The light-weight of plastics materials also make them favourable for automotive applications that call for lower fuel consumption and carbon dioxide emission. Applications of plastics components in the automotive industry have been increasing over the last decades to reduce car weight and to reduce manufacturing cost as plastics are lighter and can be processed at a high automation and low cost level.

Through this project, capabilities have been built up on polymer over moulding and in-mould painting applications for the automotive industry. Over moulded plastics samples have been successfully demonstrated and evaluated. In-mould painting plastics resins have been searched and identified, and have been successfully used in in-mould painting trials.
Experimental results on the bonding between the components of the over moulded parts show that the bonding performance can be affected by many factors such as combination of materials, process conditions, and sample pre-treatment. Good bonding can be achieved in many combinations of commercially used polymer materials. Plasma treatment can also significantly enhance the bonding performance.

6 INDUSTRIAL SIGNIFICANCE

Plastics industry is very important in supporting the automotive industry. Many of the Singapore plastics company are planning to enter or already into this sector. Leading global automotive industry players have been steadily increasing their presence here via regional headquarters, logistics & distribution centres, and R&D facilities ahead of the implementation of the Asean Free Trade Area (AFTA).

To draw alongside the opportunity, The Agency for Science, Technology and Research (A*STAR) has already setup an A*STAR Capability for Automotive Research (A*CAR) Taskforce to facilitate the collaboration between the A*STAR research Institutes and industrial players. The over moulding process is a very promising process for automotive industrial applications.

The automotive industry today is a very competitive industry. High performance, fuel efficiency, low cost, and stylish design are some of the factors that attract customers. Applications of over moulded plastics components can meet many of the demands in the automotive industry as the properties of different polymers can be better utilised and many modern design features can be easily implemented. To further develop and commercialise the over moulding technologies for automotive applications, a plan has been drafted to work with industrial partners through consortium.

REFERENCES