Development of a Green Manufacturing Process for Automotive Radiator Grill

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Summary: This work developed a film-insert moulding process for making an automotive chrome-like radiator grill in order to reduce the manufacturing cost and to avoid the environmental pollution caused by painting or plating process. The manufacturing processes mainly perform automatically from film forming, film trimming, handling, and injection moulding. One of the most important considerations is how the inserted film is held in the place in the mould cavity to avoid displacement and overlap phenomena occurring in the moulding process. A sensor-based retention mechanism that fixes the inserted films in the desired positions during the injection process was proposed instead of using vacuum, electrostatic, or other mechanical methods. In addition, process parameters including injection time, packing pressure, mould temperature, and melt temperature were also optimized using DOE, approximation, and GA optimization algorithm in order to minimize warpage, residual stress, and defect rate. The results of real manufacturing show that the cost of the automotive radiator grill made by film-insert moulding method reduces 7.8 % in comparison with the one made by a traditional chrome decorating. Furthermore, the proposed sensor-based system for adaptive fixing the inserted films can be extended into the process condition-based monitoring and self-optimizing system for the consistent quality of moulded parts. The proposed system and manufacturing process reduces the defective parts, manufacturing cost, and offers an ability of integration of functions into plastic moulding systems which enable robust technologies and enhance the manufacturing capabilities of the plastic industry.

Keywords: Manufacturing Process, Moulding, Optimization, Condition Monitoring, Adaptive Control.

1. Introduction

Green manufacturing processes have been drawing a great attention to the designers and manufactures because of the ecological issues and new environmental legislations. Film-insert injection moulding (FIM) or in-mould decorating is a relative new technique replacing for the traditional post-moulding decoration in order to cut down the manufacturing cost and to avoid the environmental pollution caused by painting or plating process [1,2]. FIM technique has been widely used in automotive industry [3,4] for decorating interior and exterior automotive parts. Although FIM for manufacturing of automotive components have been being studied and applied successfully, some problems such as short shot, overlap of inserted film, inconsistent quality of moulded part still exist in particular circumstances. This paper focuses on a practical aspect of the injection molding technology. A FIM manufacturing process for making an automotive radiator grill was developed. New advanced technology, automation, sensor-based controlling and monitoring application on injection moulding industry as well as process parameters optimization were applied to the proposed manufacturing process to make a difficult injection moulding task become successful and effective.

2. Design of the film-insert moulding process for manufacturing an automotive radiator grill

Radiator grill is one of the exterior parts in the automobile for using as a technical and aesthetic component. It used to be decorated by chrome coating in order to make it look like a bright chrome-made part. However, the manufacturing process is quite complex and harmful to the environment. For these reasons, we developed a film-insert moulding for making an automotive radiator grill. Film-insert moulding can be considered as a green manufacturing technique that can replace the traditional moulding and decorating plastic part. Figure 1 shows a comparison between a traditional manufacturing process with coating and a FIM technology. It can be seen that FIM shortens the manufacturing process, cuts down manufacturing cost, and avoids the plating and painting processes which cause air and water pollution.

The FIM process was designed with three main steps: film forming, trimming and injection moulding. The selected inserted film is a Fluorex® bright film that passes all material requirements such as UV resistance, scratch resistance, and the cleanability with high pressure power washing. The manufacturing process was performed automatically from film forming, film trimming, handling and moulding (see Figure 2). The forming operation was carried out by using a matched-metal tooling that both male and female die are used. After being formed into narrow and long 3D shapes, the films were cut out of

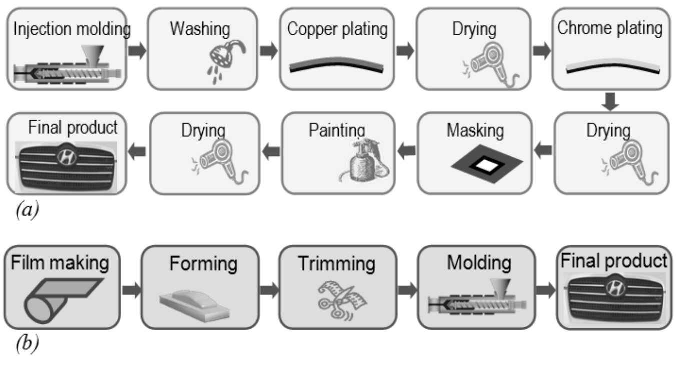
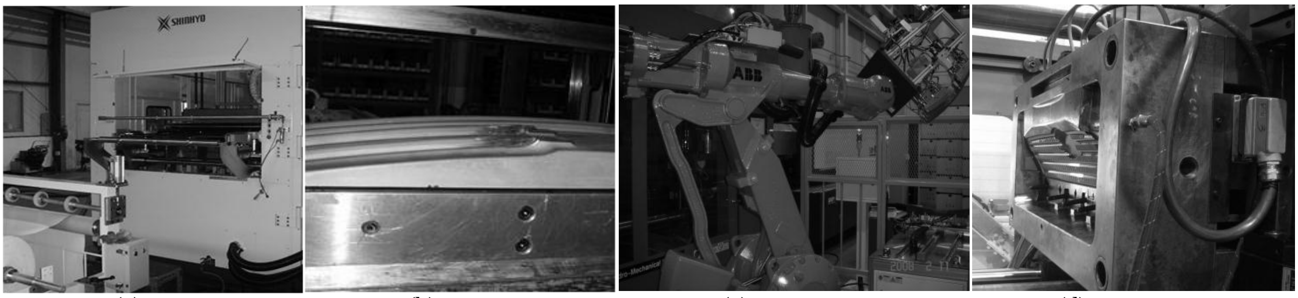


Figure 1. Traditional process of chrome plating for plastic part (a) versus in-mould decorating or film-insert moulding (b).



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

Figure 2. The manufacturing process: (a) film forming, (b) trimming, (c) film handling, and (d) injection molding.

the undesired material. A robot with a special designed tool arm is used to pick up and place six films into the mould cavity at the desired positions before injection moulding. Besides an advanced FIM production line, sensor-based retention system that is used to fix the films firmly in the mould cavity was adopted. Also, the injection moulding process parameters were optimized in order to produce the consistent quality of the product. These issues are described briefly in the next sections.

3. Development of a sensor-based retention system for adaptive fixing the inserted films

For moulding the automotive radiator grill by FIM technology, fixing the inserted film in the mould cavity is an extremely important task. The original design of electrostatic method that holds the inserted films at the desired positions during the filling process was fail. The reason is that the momentum of the resin flow, which is bigger than electrostatic force, tends to push the inserted films moving out of their desired locations. As the result, the defect rate was very high (up to 20%). To tackle this problem, we proposed a special sensor-based retention system for adaptive fixing the inserted films in the mould cavity. Although sensor-based prediction moulded part's quality in the injection mouldings had been proposed in some published works [5-7], using sensor-based mechanism for fixing inserted films in FIM is a new practical application.

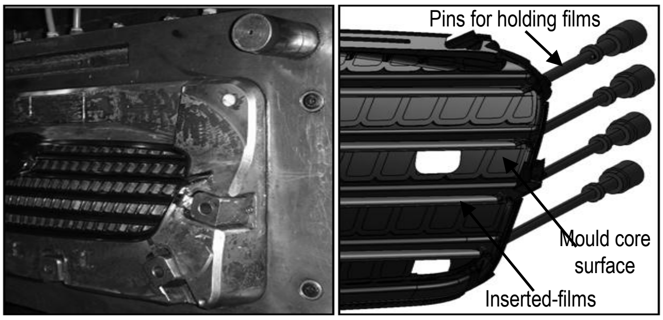


Figure 3. Retention pins mounted in the core mould that firmly holds the films in the cavity mould.

The working principle of the retention system is as follows. After the robot places the films at the desired positions in the mould cavity, the mould closes, and the pins' tip in the retention system push against the inserted films into the mould cavity's surface by a spring-force (see Figure 3&4). Next, the resin is injected in the mould cavity from a gate located in the middle of the mould. When the liquid resin reaches the pins' tip and the pressure sensors nearby the pins, the pressure at these positions increases from atmospheric pressure to a certain value. When the hydraulic pressure is large enough (more than 2 MPa as the designated value), the role of fixing of the pins must be finished as the requirement because all inserted films have been fixed at the end of filling. At the packing stage, the pins must retract so that the resin continues to fill the space at the back side of the films where occupied by the pins' tip during the filling phase. The retraction of the pin (moving from right to left as shown in Figure 4) is driven by a force generated from a solenoid. The solenoid is controlled and driven by a PLC. The piezoelectric pressure sensors (PRIAMUS 6001A1.2) are mounted near the pins' tip and give the signal to an amplifier and the PLC to determine when the plastic flow reaches the pins' tip or when the fixing pins must retract. If the pressure is in the range of 0~2 MPa, the solenoid always releases the retention pin. Different pins are controlled independently. The system works periodically according to the moulding cycle. The proposed sensor-based system works exactly and reliable.

4. Optimization of moulding process parameters

Moulding conditions or process parameters play an important role in plastic injection moulding. The quality of the moulded part is greatly influenced by the process conditions. To minimize the warpage, residual stress and reduce the defect rate, process parameters including injection time, packing pressure, mould temperature, and melt temperature were also optimized using the combination of CAE tools, design of experiment, approximation technique, and biologically inspired GA optimization algorithm [8]. Figure 5 illustrates the history plot of the optimization process that minimizes the warpage of the moulded radiator grill using GA optimization method.

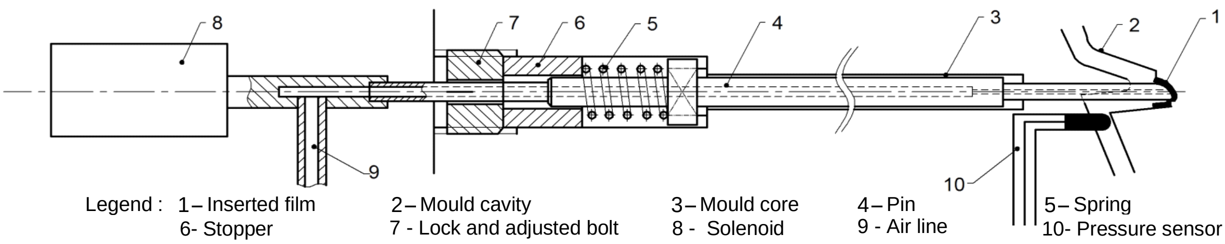


Figure 4. Sensor-based and electric-controlled mechanism for fixing the inserted film.

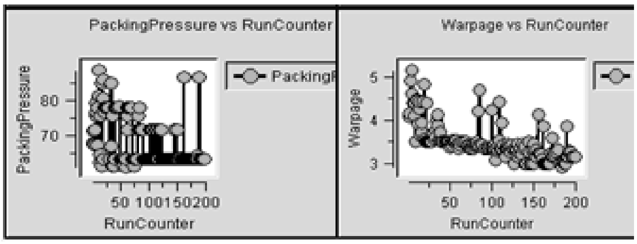


Figure 5. History plot of some variables and objective function during the optimization process using GA optimization method.

The application of the CAE numerical simulation tool in conjunction with optimization was applied to build the boundary conditions of the moulding parameter and identify the failures such as short shot or large warpage. Using the boundary conditions of the injection moulding process data and the real time processing data, the quality of moulded part can be predicted without doing the direct inspection.

5. Self adaptive monitoring and controlling system for consistent quality of moulded part

The proposed sensor-based system that fixes the inserted films can be expanded to the condition-based quality monitoring system for thermal plastic injection moulding, an on-going research project, as shown in Figure 6. Besides pressure sensors, cavity temperature sensors are installed inside the mould to collect the signals showing the mould and melt temperatures. The proposed system comprises the main block namely MouldView/ SmartMould. This main block is a real-time hardware and software system that performs the data acquisition, intelligent process analysis, and adaptive closed-loop control. The adaptive controller performs the real time, closed-loop control of injection velocity, packing pressure, mould temperature, and melt temperature that follows the simulation-based optimum setting. It receives the injection process information from the sensors and the status of the injection moulding machine, determines whether the moulded part meets the required quality based on the boundary conditions of the processing parameters. MouldView/ SmartMould module also automatically and intelligently generates appropriate processing conditions for the next injection cycle. This system considers the variation of material properties and disturbances due to the change of working environment and uncontrollable machine dynamics. It can be seen that the proposed adaptive monitoring and controlling system assures a consistent quality of the moulded part regardless of disturbance.

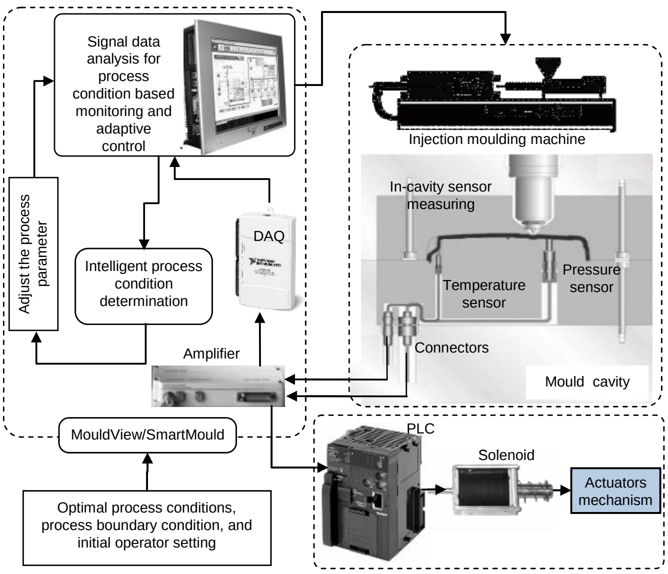


Figure 6. Self adaptive monitoring and controlling system.

6. Result and conclusions

The proposed manufacturing technique reduces the production cost per product about 7.8 % compared to the traditional injection moulding and decorating process due to a shorter manufacturing process. The benefit of FIM technique for manufacturing the radiator grill will increase if the environmental cost is included. The quality of the automotive radiator grill is assured due to the application of process parameter optimization at the design stage. The challenge of the reduction of a high defect rate caused by the dislocation of the inserted films was tackled by sensor-based technology. After applying the electrical-controlled retention system, the rate defect namely overlap significantly reduced from 20 % to around 2%. The successful application of FIM for manufacturing automotive components indirectly makes the cars to be friendly to the environment since they are being manufactured. In addition, the sensor-based approach can be integrated with the process condition monitoring and adaptive controlling system for a consistent quality of the moulded product. It is clear that the proposed system and manufacturing process reduce the defective parts, reduce the manufacturing cost, and offer an ability of integration of functions into plastic moulding systems which will enable robust green technologies and enhance the manufacturing capabilities.

Acknowledgements

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References

[1] Kim, G. et al., 2009, Prediction of the film thickness distribution and pattern change during film insert thermoforming, Polymer Engineering & Science, 49:2195-2203.
[2] Sherman, L. M., 2004, Where the Action Is: Decorating with Formable Films, Available: www.ptonline.com/articles.
[3] Zöllner, O., 2007, Plastics engineering in automotive exteriors, in Plastics in automotive engineering: exterior applications, Hanser:41-52.
[4] Baek, S. et al., 2008, Effect of processing conditions on warpage of film insert molded parts, Fibers and Polymers, 9:747-754.
[5] Huang, M.S., 2007, Cavity pressure based grey prediction of the filling-to-packing switchover point for injection molding, Journal of Materials Processing Technology, 183:419-424.
[6] Wong, H.Y., Fung, T., Gao, F., 2008, Development of a transducer for in-line and through cycle monitoring of key process and quality variables in injection molding, Sensors and Actuators, 141:712-722.
[7] Wang, K.K., Zhou, J., 2000, A concurrent-engineering approach toward the online adaptive control of injection molding process, CIRP Annals - Manufacturing Technology, 49/1:379-382.
[8] Park, H.S, Dang, X.P., 2011, Development of a fiber-reinforced plastic armrest frame for weight-reduced automobiles, IJAT, 12/1:83-92.