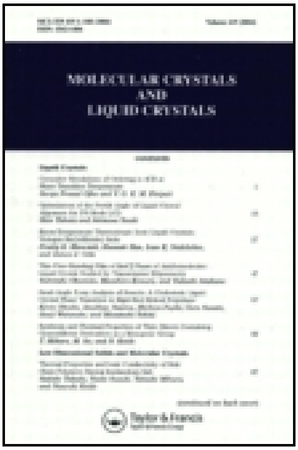

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

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Version of record first published: 24 Sep 2006

Mol. Cryst. and Liq. Cryst., 2000, Vol. 354, pp. 319-330
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The Influence of the Melt Blender on Process Parameters in Injection Moulding of ABS

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A perfectly homogenous melt is one of the prerequisites towards meeting increasingly strict quality requirements in the injection moulding. Melts can display heavy inhomgeneities downstream of the screw. including radial temperature differences and irregularities in pigment or additive distribution. This can lead to colour striation. staining, and discrepancies in the weight of products.

In the injection moulding the homogeneity of melts after they leave plastifying unit is often inadequate. It is recommended to use static mixing units in the flow channel between the plastifying unit and the nozzle to improve homogenization. In this work we studied the influence of melt blender, Sulcer SMK-X mixer, on temperature homogenization and colour distribution in the injection moulding of acrylonitrile butadiene styrene copolymer (ABS). Series of experiments were carried out with and without mixer on the Ferromatic Milacron F40 injection moulding machine. The mixer was located in front of the nozzle. The design of experiment technique was applied to minimize the number of required experiments. Barrel temperature, concentration of masterbatch, injection speed and cycle time were varied and quality of products tested by spectophotometric measurements of colour difference and mass measurements.

The results proved that introduction of Sulzer mixer had great impact on product aesthetic quality due to better temperature homogenization and colour distribution. Optimization of the process parameters has been done. Barrel temperature was reduced from 2350C to 2270C and this resulted in shorter cycle time of product production. This also shortened the down time of the machine in the case of mould change or maintenance. The better colour distribution. measured by colour difference of standard and product, was obtained with the Sulcer mixer.

Keywords: Sulcer mixer; injection moulding; ABS; design of experiments; colour difference

INTRODUCTION

In injection moulding, the screw must draw in material in granule or powder form, compact it, melt it down, homogenize it mechanically and thermally and then discharge it. In many cases these processes are accompanied by degassing and/dosage of dyestuff pigments or additives. A screw must meet all requirements of temperature and dyestuff homogenization. The homogeneity of melt after it leaves the plastifying unit is often inadequate [1]. It causes colour striation, staining and major discrepancies in mass of mouldings. To solve this problem, it is becoming increasingly common to use static mixing units, melt blenders, in the flow channel between the plastifying unit and the nozzle to improve homogenization.

The mixing action in laminar pressure flow can be substantially improved by incorporating static mixing devices in the channel. These devices split and reorient the flow and, thus, impart improved distributive mixing to the fluid. They are particularly useful for blending incompatible materials. These mixers have no moving parts, for that reason they are often referred to as motionless mixers [2].

Sulcer SMX mixer is built to meet the specific requirements of thermoplastic processing. The use of the mixer is confined to mixing tasks involving the regular spatial distribution of inhomogeneities within the melt, i.e., to distributive mixing [3].

This article discusses the influence of Sulcer SMK-X mixer on temperature homogenization and colour distribution in the injection moulding of two articles produced in acrylonitrile butadiene styrene (ABS) terpolymer.

We shall focus on the process parameter optimization and quality improvements of moldings. Theory of design of experiments will be applied to construct alinear model correlation between processing parameters and quality of the product.

EXPERIMENTS

In our work, Ferromatic Milacron F40 injection moulding machine was used with and without Sulcer SMK-X mixer. The mixer consisted of a number of mixing elements arranged in a tube. The elements consisted of a lattice of crosswise interlocking webs. A melt passing through it in laminar flow is continuously dissected into strata distributed over the pipe cross-section. The mixer containing four elements was located between the barrel and nozzle.
Two moulds have been used in the experiments: the two cavity mould No 6102120 – Pig II, and the four cavity mould No 3408002 – Female Skirt 1900 used in regular production of toys in Playmobil Ltd., Malta.

Choice of Parameters

The choice of parameters to vary and optimize was considered with respect to the expected benefits of Sulcer Mixer.
Barrel temperature (BT) was chosen as a parameter for optimization because of its influence on melt and moulding characteristics. A high barrel temperature means low melt viscosity and better mixing even without mixer, but it cause enhanced degradation of the polymer. A lower barrel temperature is desirable because of lower energy consumption and less degradation risk.
Sulcer Mixer is providing better distributive mixing and reduction in the consumption of masterbatch according to the manufacturer's literature [4]. During the tests conducted, the concentration of masterbatch (CM) was decreased and the colour difference was determined by Minolta CM – 2002 Spectrophotometer.
Since the cooling time (CT) is the biggest fraction of the cycle time its choice was related to the potential reduction of cycle time.

Injection speed (IS) controls shear rate of the melt. The defects like jetting or streaks can be controlled by it. By optimization of this parameter the improvement of moulding quality was expected.

Design of Experiments

The series of experiments were planed and carried out according to the principles of design of experiments. The theory of design of experiments leads to the construction of equations that can be used to determine the optimum direction of the acting parameters in order to satisfy the performance characteristic of the product. For the purpose of this study it was chosen a linear model with all interactions. Four parameters mentioned above were varied at lower and higher level values regarding the reference values defined in the preliminary experiments and Playmobile's mould cards. Colour difference and cycle time were measured as characteristic responses. The total number of experiments for each mould was sixteen. Five shots were collected at each experimental setting.

Mould No. 6102120 - Pig II

This mould is usually operated on an F20 machine. Since an F40 machine was used, a series of preliminary experiments had to be conducted to define the parameter values that lead to the production of good quality mouldings. Table I show the reference parameter values chosen after the preliminary experiments were conducted.

TABLE I Reference parameters for the mould Pig II on the F40 machine

	Barrel Temperature	**Concentration of Masterbatch (g/kg)**	**Cooling Time**	**Injection Speed (mm/s)**

	(0C)		(seconds)	
Settings without Sulzer Mixer	235	30	7.8	10
Settings with Sulzer Mixer	235	30	7.8	25

Mould No. 3408002 - Female Skirt 1900

This mould is usually operated on an **F40** machine. There was no need to conduct any preliminary experiments. The reference parameter values were given in the Playmobile's mould card and are presented in the Table II.

TABLE II Reference parameters for the mould Female Skirt 1900 on the F40 machine

	Barrel Temperature (0C)	**Concentration of Masterbatch (g/kg)**	**Cooling Time (seconds)**	**Injection Speed (mm/s)**
Settings without Sulzer Mixer	225	25	7	80
Settings with Sulzer Mixer	225	25	7	80

Visual testing of the mouldings has been done according to the Internal Quality Standards established by Playmobile. The samples were rated between one as the best and five as the worst. The colour tag, to which the samples were compared, was rated as three. The main defects checked were flow lines and colour difference. The colour difference ΔE, defined as the difference between chromatic and achromatic values of the sample under test and the standard colour tag, was measured with Minolta 2002 Spectrophotometer. The standard colour tag was made with the same concentration of masterbatch as that of the samples.

RESULTS

The range of parameters on F40 machine was determined in preliminary experiments for mould No 6102120-Pig II, so that it would produce mouldings within the specification. The final experiments gave the linear models and response surfaces for the prediction of responses, as well as indication of the direction of the optimum.

Empirical Modeling

Once the number of levels of the parameters and their range of values were determined, an experimental technique was devised in order to narrow the number of experiments. The general equation of the empirical model is shown in Equation 1. The true function f is unknown, and the approximation of the true function is done by graduating function f by Taylor's series [5]. The linear model with all interactions takes into account additive linear effects plus all potential interactions. This model has 2k unknown coefficients, which will have to be determined from at least sixteen experiments. Hadamard Matrix is a useful tool in design of an experiment representing all the features necessary in the procedure of construction of linear model.

$$Y_{exp} = \mathbf{f}(P_1, P_2, P_3 \ldots P_k) + \epsilon \qquad (1)$$

Y_{exp} is the experimental response.
f is some function.
$P_1, P_2, P_3 \ldots P_k$ are input variable factors of the study predictors and

ϵ is the experimental error.

Prediction of a Response and Optimization

Table III represents the parameter values used for the prediction of response and process optimization. The barrel temperature was decreased relative to the reference value, since this could result in lower energy consumption and decrease in the probability of melt degradation. The concentration of masterbatch was also decreased because this would be cost effective. Cooling time was decreased to achieve a higher production rate and cost impact. Injection speed was increased with expectation that it would also increase the production rate.

TABLE III – Parameter values used on the F40 machine with and without Sulcer mixer

	Pig II		**Female Skirt 1900**	
	Low (-1)	**High (+1)**	**Low (-1)**	**High (+1)**
BT (0C)	225	215	205	215
CM (g/kg)	25	30	20	25
CT (seconds)	6.6	7.8	6	7
IS (mm/s)	30	35	90	100

Linear model with all interactions takes into account additive linear effects plus all potential interactions. It is presented by Equation 2, and represents the parameter contributions to the product or process characteristics.

$$Y = b0 + b1(BT) + b2(CM) + b3(CT) + b4(IS) + b5(BTCM) + b6(BTCT) + b7(BTIS) + b8(CMCT) + b9(CMIS) + b10(CTIS) + b11(BTCMCT) + b12(BTCMIS) + b13(BTCTIS) + b14(CMCTIS) + b15(BTCMCTIS) \quad (2)$$

BT, CM, CT and IS represent the independent parameters while the parameters in the brackets represent the interactions. For example, BTCT is the interaction between barrel temperature and cooling time. The values b0 – b15 quantify the contribution of independent parameters or interactions to the moulding colour difference or process cycle time.

Mould No. 6102120 – Pig II - Linear models for injection moulding without Sulzer mixer

Equation 3 represents linear equation for the colour difference response obtained for the experiments carried out without mixer. The barrel temperature (BT) which has a coefficient of –0.174 gives the highest contribution from independent parameters

Y colour difference = 3.274 – 0.174(BT) + 0.004(CM) + 0.076(CT) + 0.063(IS) – 0.049(BTCM) – 0.143(BTCT) – 0.168(BTIS) + 0.183(CMCT) + 0.103(CMIS) + 0.112(CTIS) – 0.216(BTCMCT) – 0.163(BTCMIS) – 0.189(BTCTIS) + 0.204(CMCTIS) – 0.117(BTCMCTIS) (3)

The linear model with all interactions representing the cycle time in Equation 4 proves that the cooling time and injection speed are the most influential parameters. The shortest cycle time is obtained with barrel temperature of 2150C and concentration of masterbatch of 30g/kg .

Y cycle time = 13.316 – 0.003(BT) – 0.009(CM) + 0.591(CT) – 0.057(IS) – 0.003(BTCM) – 0.003(BTCT) + 0.007(BTIS) – 0.009(CMCT) + 0.001(CMIS) – 0.007(CTIS) – 0.028(BTCMCT) – 0.001(BTCMIS) + 0.007(BTCTIS) + 0.001(CMCTIS) – 0.001(BTCMCTIS) (4)

Linear Models for Injection Moulding with Sulzer Mixer

Equation 5 represents linear model of colour difference obtained for injection moulding with Sulcer mixer. The lowest value for ΔE was 2.06 which was reached when the concentration of masterbatch and injection speed were set at 30g/kg and 30mm/s respectively.

Y colour difference = 46.43 – 0.81(BT) – 7.71(CM) – 0.43(CT) + 0.87(IS) – 0.87(BTCM) – 0.35(BTCT) + 0.43(BTIS) + 1.87(CMCT) – 0.43(CMIS) + 0.29(CTIS) + 2.19(BTCMCT) + 1.45(BTCMIS) + 0.45(BTCTIS) – 0.41(CMCTIS) + 1.19(BTCMCTIS) (5)

The shortest cycle time achieved with the Sulzer Mixer was 13.8 seconds. From Equation 6, the greatest effect on cycle time have the cooling time and injection speed. This is the same dependence as in experiments when the Sulzer Mixer was not used.

Y cycle time = 14.525 – 0.013(BT) + 0(CM) + 0.575(CT) - 0.025(IS) + 0.013 (BTCM) + 0.013(BTCT) + 0.013(BTIS) + 0(CMCT) + 0(CMIS) – 0.075(CTIS) – 0.012(BTCMCT) – 0.013(BTCMIS) – 0.013(BTCTIS) + 0(CMCTIS) + 0.013(BTCMCTIS) (6)

Figure 1 represent 2D Response Surface, where the response is colour difference, which is read from the contours formed from the plot. The concentration of masterbatch and injection speed ware varied parameters and barrel temperature and cooling time were kept constant.

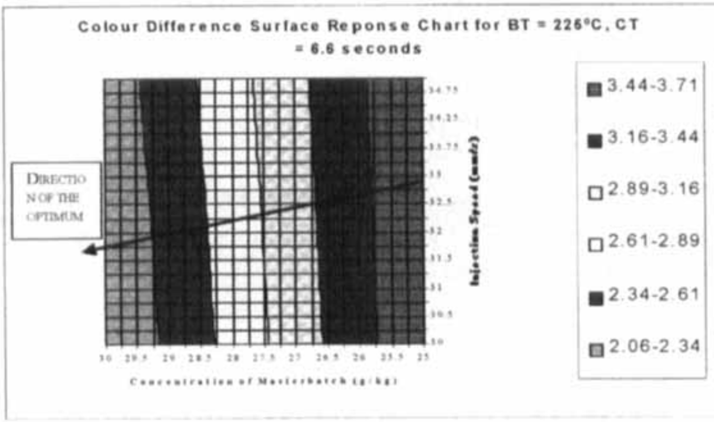
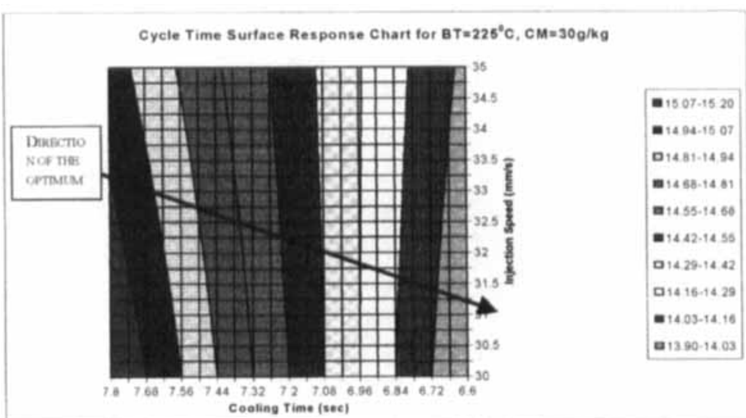


FIGURE I Representation of 2D response surfaces of colour difference

Figure II shows example of cycle time optimization. Simultaneous change of cooling time and injection speed, while the barrel temperature and concentration of masterbatch are kept constant leads to shorter cycle time as the parameters are decreased. Injection speed has minimal effect comparing with cooling time. Therefor, to optimize the cycle time at given barrel temperature it is necessary to decrease cooling time as much as possible.

FIGURE II Representation of 2D response surfaces of cycle time



Mould No. 3408002 – Female Skirt 1900 – Linear Models for Injection Moulding without Sulcer Mixer

Equation 7 represents the dependence of colour difference on processing parameters. The barrel temperature and cooling time has greatest contribution to the colour difference.

Y colour difference = 4.814 – 0.133(BT) – 0.069(CM) + 0.123(CT) + 0.038(IS) – 0.104(BTCM) – 0.117(BTCT) + 0.086(BTIS) + 0.049(CMCT) – 0.091(CMIS) + 0.029(CTIS) – 0.008(BTCMCT) + 0.049(BTCMIS) – 0.001(BTCTIS) + 0.066(CMCTIS) + 0.028(BTCMCTIS) (7)

Equation 8 represents the dependence of cycle time on processing parameters. The cooling time and the injection speed are the most influential, as shown in linear model.

Y cycle time = 13.609 + 0.011(BT) – 0.004(CM) + 0.496(CT) – 0.014(IS) + 0.004(BTCM) – 0.001(BTCT) - 0.011(BTIS) + 0.014(CMCT) + 0.009(CMIS) + 0.009(CTIS) + 0.001(BTCMCT) + 0.016(BTCMIS) + 0.001(BTCTIS) + 0.011(CMCTIS) + 0.009(BTCMCTIS) (8)

Linear Models for Injection Moulding with Sulzer Mixer

From Equation 9 it is evident that concentration of the masterbatch and cooling time have the biggest influence on colour difference. This is in contrast with dependence in equation 7 where the barrel temperature has bigger influence than concentration of masterbatch.

Y colour difference = 4.398 – 0.094(BT) – 0.135(CM) + 0.126(CT) + 0.039(IS) – 0.076 (BTCM) – 0.03(BTCT) - 0.06(BTIS) + 0.114(CMCT) + 0.086(CMIS) + 0.005(CTIS) + 0.123(BTCMCT) + 0.028(BTCMIS) + 0.001(BTCTIS) - 0.068(CMCTIS) - 0.106(BTCMCTIS) (9)

Equation 10 represents linear model of cycle time obtained in experiments with Sulcer mixer. Cycle time is the most affected by the cooling time and concentration of masterbatch.

$$Y\ cycle\ time = 13.808 + 0.01(BT) - 0.02(CM) + 0.48(CT) + 0.018(IS) + 0.013(BTCM) + 0.008(BTCT) + 0(BTIS) + 0.013(CMCT) + 0.01(CMIS) + 0(CTIS) + 0.01(BTCMCT) + 0.02(BTCMIS) - 0.002(BTCTIS) - 0.008(CMCTIS) + 0(BTCMCTIS) \quad (10)$$

CONCLUSIONS

From the tests carried out it can be concluded that introduction of melt blender, Sulcer mixer, into the processing of ABS contributed immensely to the quality of mouldings and cost savings. Temperature homogenization of melt and masterbatch distribution was such that produced melt was with no temperature and colour variation. The barrel temperature was decreased what resulted in 5% decrease of cycle time. The decrease in barrel temperature resulted also in a shorter downtime and start-up of the machine. Lower reject rates for both products additionally contributed to cost savings.

A mixer also reduced the influence on product quality of deviation from optimum machine adjustment, and thus stabilized the entire production process.

Acknowledgment

The authors thank Playmobile Malta for sponsoring and interest in this project.

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