A test series supplies different moulded-part fractions, a statistical analysis program the instructions for efficient crisis management

First-aid Instructions

Quality Assurance. If moulded-part quality in injection moulding goes off course, rapid action is required. A systematic analysis of the relationships between machine settings and component quality makes it possible to identify for whole component families the optimum measures that need to be taken to return quickly and efficiently to a stable operating range.

The stable operating range in the production of a high-quality injection moulding is sometimes very narrow. Even small changes in the production cycle can lead to rejects. The routine responses of machine setters usually permit rapid correction but these are based on empirical values and not on an analysed strategy. In the end, every practitioner in injection moulding knows from everyday practice how the main settings, such as injection rate, holding pressure time or the switchover point from injection to holding pressure, affect the moulding and recognises the measures that need to be taken if defective parts are being produced.

What machine setters learn from experience can be mathematically analysed for a whole product family of injection moulded parts. Different methods can be used for this, such as statistical test planning and correlation and regression analysis. A study such as this on a car body blanking plug made from thermoplastic elastomer (TPE) was carried out at the Institut für Polymerwerkstoffe und Kunststofftechnik der Technischen Universität Clausthal (Institute for Polymer Materials and Plastics Technology at the Technical University of Clausthal, Germany). The result, a so-called secondary measures list, can be used by injection moulders directly to improve production.

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Careful Selection of the Relevant Parameters

The analysis starts by selection of the relevant influencing parameters. All the phenomena known to have a significant influence on component quality must be recorded and their relative importance evaluated. In this activity, close collaboration between Quality Assurance, Production and Toolmaking is generally recommended in order to pool all the available experience with the mould or product family. In the present example, five main parameters were selected.

These parameters were assigned upper and lower limits; within these, equal steps were defined. This procedure is explained in Table 1. The settings are given clear abbreviations for later mathematical processing, e.g. A1 = injection rate = 20 cm^3/s. With these parameters, it is now possible in principle to run all possible combinations of parameters and values:

- settings for test 1: A1, B1, C1, D1;
- settings for test 2: A2, B1, C1, D1;

Parameter		Step 1	Step 2	Step 3	Step 4
A	Injection rate	20 cm^3/s	25 cm^3/s	30 cm^3/s	35 cm^3/s
B	Holding pressure	400 bar	500 bar	600 bar	–
C	Holding pressure time	0.6 s	0.8 s	1.0 s	–
D	Changeover point	6 cm^3	8 cm^3	10 cm^3	–
E	Back pressure	20 bar	40 bar	60 bar	–

Table 1. Selected influences, parameters and parameter steps for machine setting. The parameters are assigned upper and lower limits with equidistant steps in between

Parameter	Step 1	Step 2	Step 3	Step 4
a: Flash formation	< 0.19 mm	0.2 ... 0.49 mm	0.5 ... 1 mm	> 1 mm
b: Warpage [maximum]	< 0.19 mm	0.2 ... 0.99 mm	1 ... 5 mm	> 5 mm
c: Defect	no	yes	–	–
d: Overweight	< 0.99 %	1 ... 4.9 %	5 ... 10 %	> 10 %
e: Underweight	< 0.99 %	1 ... 4.9 %	5 ... 10 %	> 10 %

Table 2. Selected quality characteristics, parameters and parameter steps for the moulded part. The grading is based on quality assurance reject criteria, step 2 means "reject"

Measure / Secondary effect	External flash formation: Reduce holding pressure	Gate flash formation: Shorten holding pressure time	Overweight: Shorten holding pressure time	Underweight: Increase holding pressure	Defect: Lengthen holding pressure
External flash		Reduce injection rate	Reduce injection rate	Reduce injection rate	Reduce holding pressure
Gate flash	Shorten holding pressure time		Shorten holding pressure time	Shorten holding pressure time	Increase holding pressure
Overweight	Shorten holding pressure time	Shorten holding pressure time		Shorten holding pressure time	Lengthen holding pressure time and increase holding pressure
Underweight	Reduce back pressure	Reduce back pressure	Reduce back pressure		Increase holding pressure
Defect	Lengthen holding pressure time	Increase holding pressure	Lengthen holding pressure time	Lengthen holding pressure time	

Table 3. The list describes what measures must be taken to eliminate a fault and at the same time counter an adverse effect of the first measure

- settings for test 3: A3, B1, C1, D1 right through to
- settings for test n: An, Bn, Cn, Dn.

To reduce the large number of tests, a statistical test plan is developed.

A Statistical Test Plan Saves Time and Cuts Costs

In the mathematical theory of statistics there is a series of statistical test plans that can be used to reduce the large sample size of a measuring range to a few relevant tests with the same informative value. In the present studies, the total number of 243 tests was reduced to 26 representative tests. For this purpose, a determinant-optimised test plan (D-optimised plan) was selected.

To develop a test plan like that selected, either the mathematical principles of statistics can be used [1, 2] or one of the numerous software solutions available on the market. In the present case, both development of the test plan and subsequent analysis were carried out using the RS/1 Series program [3].

The injection moulded part selected belongs to a product family of blanking plugs made from TPE that are used in the vehicle underbody area. The general production conditions for the various plugs are so similar as regards the materials and injection moulds used, their geometry and any undercuts that analysis of the selected part can be used to represent the whole product family. Fig. 1 shows the two-cavity mould used with a latch and hot runner.

The mouldings were produced in the Institute's pilot-scale facility on a Demag Ergotech 60-370/200 injection moulding machine with a clamping force of 600 kN and NC4 control system (manufacturer: Demag Plastics Group, Wiehe/Germany). The settings in the previously mentioned test plan were used for production. In each test, 30 components were produced with each machine setting, from which five random samples were taken to evaluate quality.

Parameterisation, i.e. determination of the relevant criteria, also had to be carried out for the quality of the components produced. The quality parameters chosen were flash formation, overweight, underweight, defects and warpage. These parameters are listed in a table (Table 2).

After weighing, measuring and visually inspecting the components, the quality parameters were related to the machine settings. From this a comparison in the following form resulted:

- test 1 (settings A1, B1, C1, D1) supplies a component of quality a1, b2, c1, d1, e1;
- test 2 (settings A3, B2, C1, D3) supplies a component of quality a3, b1, c1, d3, e1;
- etc.

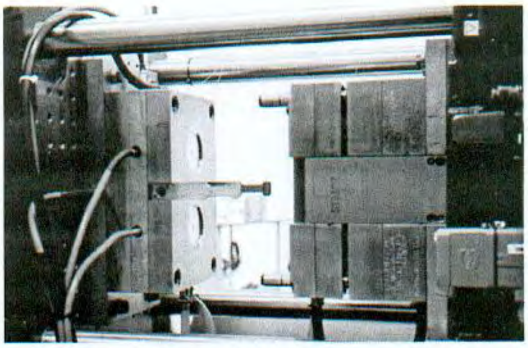

Fig. 1. Mass production mould for blanking plugs

Calculation Links Input Factors with Component Quality

If all input and quality factors are compared, two matrices are formed with their respective characteristics. Linking these matrices involves analysing all the statistical data on the relationships between the machine settings and quality of the component produced, assuming that ambient conditions do not change unacceptably.

Analysis of the two matrices requires considerable mathematical input and is best left to the previously mentioned evaluation software, which filters out the dependencies of the matrix links. Correlation and regression calculations are used as the basis for this. While a correlation calculation assigns a number to the quantitative dependency of two dependent values, the result of a regression analysis is a defined mathematical relationship. This must then be represented in a suitable form.

The relationships are clearest in the so-called Pareto chart of the main effect. This

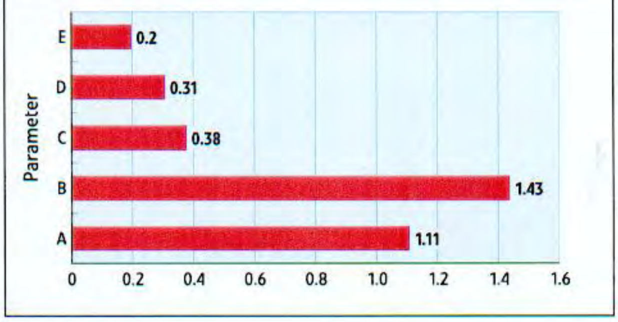

Fig. 2. The result shows which parameters influence flash formation on the moulding and to what extent

makes plain what machine settings exert what influence on a quality parameter of the component, most. Fig. 2 shows what characteristics influence flash formation on the component and how strongly the influence is to be rated. As can be seen, the formation of flash on the component can be most effectively influenced by changing the setting B (= holding pressure). The second most important influence on flash formation according to this representation is setting A (= injection rate) and the lowest the setting E (= back pressure).

Eliminating Faults and Countering New Faults

The process analysis shows that a machine setting cannot be changed separately without influencing other quality parameters. It is perfectly possible that changing a setting will indeed eliminate a fault that has occurred but at the same time provoke another, perhaps far worse. It is therefore necessary to create a "secondary" measures list. This describes what measures must be taken to eliminate a fault and counter an effect of the first measure. Table 3 shows an example of such a measures list for the analysed process.

The first line of this table gives the most effective measure from the first list and matches it with a possible secondary effect. Example: a fault has occurred in a component. The first measure must be to increase the holding pressure. As a result of this, the component might, for example, start being underweight. The secondary measure is therefore an additional increase in holding pressure so that either the component is brought back within the tolerances or the machine is on course to restore a stable operating range.

The study not only makes clear that the influence of the many machine settings and disturbing variables in the injection moulding process can be analysed at an acceptable cost but that from this analysis a list of measures for rapid and effective fault elimination can be generated, which is relevant to a whole family of similar components.

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This list of measures has been tested and validated for the automotive industry in collaboration with the supplier TRW, Hildesheim Emmerke. It made a significant contribution to improving production and minimising the reject rate. ■

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