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ORIGINAL ARTICLE

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Reducing the effects of weldlines on appearance of plastic products by Taguchi experimental method

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Abstract Weldlines influence not only strength of injection products but also the appearance of the products. This paper studies the effects of processing parameters on the appearance of weldlines by Taguchi experimental design method. Weldlines are obtained by the right door of copy machine which is modeled with three gates. The pictures of molding products are taken by digital camera. The samples of products and weldlines are extracted by software photoshop. The hue values of the samples of products and weldlines are calculated by software matlab. The visibility of weldlines is defined with the difference of the hue values of products and weldlines. By analysis, it turns out melt temperature, injection velocity, and injection pressure are the main factors which influence the appearance of weldlines.

Keywords Appearance · Taguchi experimental method · Weldlines

1 Introduction

Weldlines are one of the defects in plastic injection molding, which are melt lines converged by two or more than two melts. Weldlines often result from the products with a through hole or modeled with multi-gates. Weldlines influence not only the strength of the products but also the appearance of the products. At the position of weldlines, the tensile strength and the impact strength of the products reduce and visible lines emerge on the exterior surfaces of the products. For most of the products, weldlines are unacceptable. Therefore, they are avoided at the utmost in product design, mold design, and processing conditions setting. There are many analyses on previous documents about the strength of weldlines, but it is rare about the appearance of weldlines. In fact, most plastic products are loaded with weak forces, which don't demand high strength of products. The strength of emerging weldlines can meet the requirement of applied loads. A good many plastic products are used outside. It is important to require a good appearance on them. Then for the products with inevitable weldlines, the visibility of weldlines should be decreased as good as possible, the weldlines should occur on internal surfaces of products or be too weak in visibility to be observed by eyes. For multi-gates products, occurrence of weldlines is inevitable. When it is impossible to change the locations of weldlines by adjusting the locations of gates, it can alleviate the visibility of weldlines by adjusting processing conditions.

The majority of studies on weldline in the previous documents is about weldline strength. Liu et al. [1] optimizes weldline strength of injection products based on Taguchi experimental matrix method. The weldlines are obtained by a plate centered with a through hole. The weldline strength is executed by 4.1 injection machine. After molding, melt temperature is confirmed to be the main factor affecting weldline strength. Kagan [2, 3] has an analysis of mechanical property of weldlines. Weldline strength of reinforced and non-reinforced nylon is investigated. It turns out they were approximately equal. The position of weldlines is predicted by software moldflow. Du [4] studies the mode of injection filling by means of simulation analysis. The details of weldlines and airtraps are given. Turng and Kharbas [5] investigates the effects of processing conditions on weldline strength with processing parameters of melt temperature, shot size, supercritical fluid level, and injection speed. It turns out the former three parameters are the main factors affecting weldline strength. Huamin and Degun [6, 7] puts forward a high effective algorithm determining the position of weldlines. Weldline strength is evaluated by neural network method. Weldline strength is described by the knitting coefficient of weldlines. Converging angle, orientation coefficient, and viscosity coefficient are the parameters of affecting knitting coefficient.

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In design of products and molds, predicting occurrence and severity of weldlines is a measure of avoiding and eliminating them. Injection molding analyzing software moldflow can simulate molding process of injection products. By filling analysis of plastic melt, the result of weldline defect is given. However, moldflow only can give the location information of weldlines on products and can't give strength and visibility of weldlines. It should combine the simulation method with experiences to evaluate weldlines.

This paper takes the influence of weldlines on appearance of products into account, analyzes the parameters of affecting appearance of weldlines. The main factors of affecting appearance of weldlines are determined. The combination of the optimized processing conditions is given to alleviate the visibility of weldlines.

2 Experiment

Taguchi [8] experimental method is a sort of experimental design method, which arranges experiments by given an orthogonal table in advance and comes to a better conclusion through less runs of experiments. Orthogonal table is a sort of regularly formalized and standardized table, which has the characteristic of equal combination. Thus it can be sampled equally. By minority of representative experimental data, the statistics are executed and the best experimental conditions are found out. Orthogonal experiments select the parameters affecting experimental target as factors. Each factor has several levels. Then orthogonal table is selected by the number of factors and levels. The experiment is organized by the chosen orthogonal table. According to experiences, melt temperature, injection pressure, and injection speed are chosen as main factors affecting visibility of weldlines. Each factor has three levels. As following Table 1. The constitutive orthogonal table is as following Table 2.

Chosen material of experiment is PP without fillings. Selected product is the right door of copy machine as shown in Fig. 1. The size of the product is 400186 × 86 × 2.6 (length × width × height × thickness) mm. It shows a product with multi-gates in Fig. 1. The injection system of the product has three gates, one at the center of the product and the other two at the sides of the product separately. Since the weldlines occur at convergence of two flows of melts, three weldlines are formed, one weldline between the center gate and the other two separately at each side gate. The model of used injection machine is HTB 450X/1J2.

Table 1 Factors and levels of experiment

Factor Level	Melt temperature (°C)	Injection speed (g/s)	Injection pressure (MPa)
level 1	200	30	100
level 2	220	40	90
level 3	240	50	80

Table 2 Constitutional orthogonal table of experiment

Factor level run	Melt temperature (°C)	Injection speed (g/s)	Injection pressure (MPa)	e1
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

3 Collect experimental data

A digital camera was used to take pictures of samples of weldlines. Figure 2 is a picture of a sample of weldline taken by digital camera. There is a leaned weldline near the upper right of the red label. The file form saved by digital camera is jpg. Visibility of weldlines is due to the difference between the hue of weldlines and the hue of the non-weldline region of the product. The more different the hues are, the more visible the weldlines are. By software photoshop, the samples of weldlines and the non-weldline region are taken separately. The size of the sample is 17.63×0.17 cm. Saved file format is jpg. Figure 3a,b are the samples of non-weldline region and weldline region separately. They have different H values. Owing to jpg form only stored with RGB information, it needs to turn values of RGB into values of HSV by the function rgb2hsv of software matlab. HSV (hue, saturation, brightness) of weldline and non-weldline regions is calculated. H values of samples are obtained by the image processing toolbox of matlab. Due to the difference of H value at each point of the sample, the average value of all the points of the sample is represented as the H value of the whole sample. H values of all the points of the whole sample are averaged by matrix average function mean2 and the average value of H value is obtained. The difference of the H value of weldline and

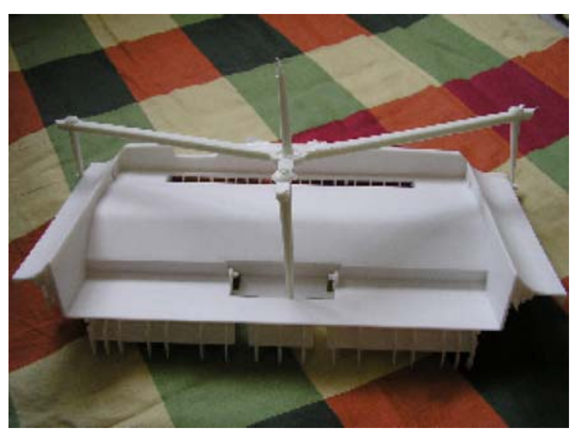

Fig. 1 Product with injection system

Fig. 2 The photo of sample with weldline taken by digital camera

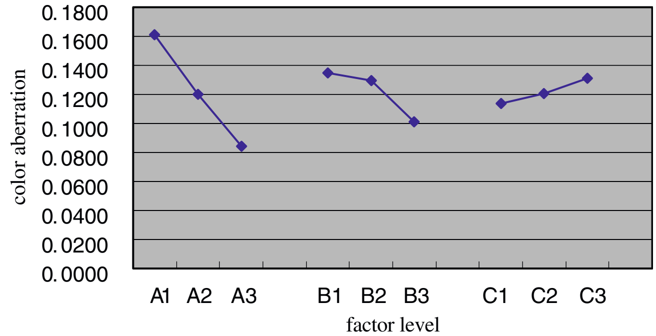

Fig. 4 The affects of all factor level on visibility of weldlines`

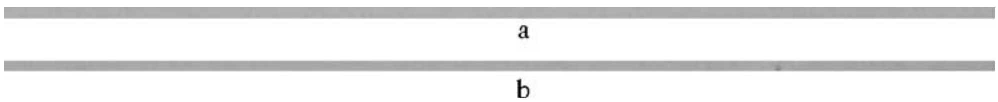

Fig. 3 The sample of the weldline region and the sample of the non-weldline region taken by photoshop

non-weldline regions is defined as color aberration. Visibility of weldlines is expressed by color aberration. The bigger the color aberration is, the bigger the visibility of the weldlines is.

4 Results and conclusion

HSV values of samples of weldline and non-weldline regions are calculated by matlab. H value is hue, S value is saturation, and V value is brightness. It only takes the main factor H value into account due to H value mainly affecting visibility of weldlines. Table 3 shows the results of H value at each experimental level. Thereinto, no1, no2, and no3 represent three repeated runs at the same level, b represents the sample of weldline region, and r represents the sample of non-weldline region. Color aberration is the difference of H value of non-weldline region and H value of weldline region, such as, Hno1=Hno1b–Hno1r. The total color aberration is a sum of the three color aberrations, i.e., HT=Hno1+Hno2+Hno3.

By the statistic of average color aberration at all levels, Table 4 is given. Thereinto, K_{1j}, K_{2j}, K_{3j} express the sum of color aberration at the first level, the second level, and the third level separately. The subscript j expresses the factor A, B, C and e. For melt temperature,

$$K_1 = H_{T1} + H_{T2} + H_{T3} = 0.5063 + 0.5281 + 0.4133 = 1.4477$$

$$K_2 = H_{T4} + H_{T5} + H_{T6} = 0.3594 + 0.4224 + 0.3004 = 1.0822$$

$$K_3 = H_{T7} + H_{T8} + H_{T9} = 0.3457 + 0.2143 + 0.1970 = 0.7570$$

$$Q_j = \left(K_{1j}^2 + K_{2j}^2 + K_{3j}^2\right) \Big/ (r \times k) = \left(K_{1j}^2 + K_{2j}^2 + K_{3j}^2\right) \Big/ (3 \times 3) = \left(K_{1j}^2 + K_{2j}^2 + K_{3j}^2\right) \Big/ 9$$

Table 3 The results of H value

Run	Level	Hno1b	Hno2b	Hno3b	Hno1r	Hno2r	Hno3r	Aberrat-ionHno1	Aberrat-ionHno2	Aberrat-ionHno3	Aberrat-ionH_T
1	1111	0. 4491	0. 4612	0. 4526	0.2793	0.2925	0.2848	0.1648	0.1727	0.1738	0. 5063
2	1222	0. 3996	0. 3991	0. 3995	0.2235	0.2212	0.2254	0.1721	0.1699	0.1621	0. 5281
3	1333	0. 4623	0. 4621	0. 4662	0.3231	0.3260	0.3282	0.1290	0.1219	0.1350	0. 4133
4	2123	0. 4540	0. 4590	0. 4598	0.3331	0.3402	0.3401	0.0999	0.1088	0.1097	0. 3594
5	2231	0. 4404	0. 4308	0. 4354	0.2974	0.2912	0.2956	0.1330	0.1396	0.1398	0. 4224
6	2312	0. 3846	0. 3877	0. 3879	0.2853	0.2860	0.2885	0.1082	0.1067	0.1134	0. 3004
7	3132	0. 4110	0. 4077	0. 4096	0.2958	0.2952	0.2916	0.1052	0.1125	0.1080	0. 3457
8	3213	0. 3987	0. 3948	0. 3968	0.3274	0.3239	0.3247	0.0763	0.0709	0.0721	0. 2143
9	3321	0. 4009	0. 4018	0. 4069	0.3379	0.3354	0.3393	0.0630	0.0664	0.0676	0. 1970

Table 4 Statistic data of color aberration at all levels

Factor Statistic data	Melt temp A	Injection speed B	Injection pressure C	e
K_{1j}	1.4477	1.2114	1.0210	1.1257
K_{2j}	1.0822	1.1648	1.0845	1.1742
K_{3j}	0.7570	0.9107	1.1814	0.9870
K_{1j}^2	2.0958	1.4675	1.0425	1.2672
K_{2j}^2	1.1712	1.3568	1.1761	1.3788
K_{3j}^2	0.5730	0.8294	1.3957	0.9742
Q_j	0.4267	0.4060	0.4016	0.4022
S_j	0.0265	0.0058	0.0014	0.0021
f_j	2	2	2	2
V_j	0.0133	0.0029	0.0007	0.0010
F_j	123.1531	27.0123	6.7285	9.7371

r Repeated number of the same level, r=3
n The number of experimental conditions, n=9
k Repeated number of each run, k=3
T Sum of color aberrations, $T = \sum_{i=1}^{9} H_{Ti}$
CT Correction term, $CT=T^2/(n\times k)=T^2/(9\times 3)=T^2/27$
S_j Q_j-CT, Variance
f_j Degree of freedom for factors
V_j (S_j/f_j), Mean square deviation
f_{e2} $n(k-1)=9\times(3-1)=18$
f_e $f_{e1}+f_{e2}=2+18=20$

$$S_{e2} = \sum_{i=1}^{n}\sum_{j=1}^{k}\left(x_{ij}^2\right) - \frac{\sum_{i=1}^{n}\left(\sum_{j=1}^{k} x_{ij}\right)^2}{k} = 0.00005453$$
$$S_e = S_{e1} + S_{e2} = 0.0021 + 0.00005453 = 0.00215453$$
$$V_e = S_e/f_e = 0.00215453/20 = 0.0001077265$$
$$F_j = V_j/V_e$$

Look up Table [8], F0.10(2,20)=2.59; $F_{0.25}(2,20)=1.49$.

$F_A>F_{0.10}(2,20)$; $F_B>F_{0.10}(2,20)$; $F_C>F_{0.10}(2,20)$, therefore, the three factors all are marked factors affecting visibility of weldlines (Fig. 4).

Table 5 Average color abberration at all levels

Factor Average color aberration	A	B	C	e1
$K_{1j}/(r\times k)$	0.1609	0.1346	0.1134	0.1251
$K_{2j}/(r\times k)$	0.1202	0.1294	0.1205	0.1305
$K_{3j}/(r\times k)$	0.0841	0.1012	0.1313	0.1097

The average value of color aberration of factors at all levels is calculated and shown at Table 5. Figure 3 is drawn according to Table 5. The effects of each factor on color aberration are shown in Fig. 3. Among them, melt temperature is the most important factor. Color aberration decreases along with an increase of temperature. The next two important factors are injection speed and injection pressure, color aberration decreases along with an increase of injection speed and injection pressure. Weldlines are formed by the meeting of two melts, the meeting interface of two melts decides the form of weldlines. When the melt temperature is high, the activity of the polymer segment is strong, the segments of two melts penetrate each other through the interface, a broad melt band is formed on the two sides of the interface, most segments maintain the former flow direction, some segments deviate the former direction as the block of the interface, the change of general orientation of segments is not big. When melt temperature is low, the activity of the polymer segment is weak, the ability of penetrating the interface is weak, most segments deviate on the interface, the change of general orientation is big, a shallow band is formed on the two sides of the interface. The change of orientation of polymer segments influence the visibility of weldlines greatly. Since the change of flow orientation, the reflection angle and reflection ratio of polymer on the interface change. It makes the reflection different between the interface and other parts of polymer and a visible melt line is formed. The bigger the change of orientation is, the bigger the difference of reflection is, and the more obvious the weldline is. So the higher melt temperature enhances the melting of segments and decreases the change of flow orientation and reduces the visibility of weldlines. As well, improving injection speed and injection pressure enhance the ability of penetrating the interface of segments and decrease the change of orientation, the visibility of weldlines is reduced.

Then the best optimized level combination is A3B3C1 for the minimum color aberration. However in practice, it should take flashes and jetting into account so that actual production perhaps is under the level.

5 Verification experiment

Chosen best optimized level combination, the experiment is executed to verify the conclusion. Chosen experimental parameters are melt temperature 240°C, injection speed 60 g/s, injection pressure 100 Mpa. Given experimental data is shown in Table 6.

Thereinto, average color aberration Have=(Hno1+Hno2+Hno3)/3=(0.0619+0.0659+0.0601)/3=0.0626, the

Table 6 Experimental data at optimal level combination

Hno1b	Hno2b	Hno3b	Hno1r	Hno2r	Hno3r	Color aberration Hno1	Color aberration Hno2	Color aberration Hno3	Color aberration Have
0.3275	0.3274	0.3277	0.2656	0.2615	0.2676	0.0619	0.0659	0.0601	0.0626

value is smaller than those of other level combination. It is the best level combination.

6 Conclusion

By Taguchi experimental method, the three main processing parameters affecting visibility of weldlines were investigated. It turned out that melt temperature, injection speed, and injection pressure all can be used to adjust visibility of weldlines. Melt temperature, injection speed, and injection pressure are the marked factors affecting visibility of weldlines. The higher melt temperature and injection speed are, the lower the visibility of weldlines. Injection speed is a factor affecting visibility of weldlines also. Visibility of weldlines can be decreased by increasing injection speed. However, the factor is not more marked than the other two factors.

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