Accuracy of castings manufactured by
the lost wax process

The way wax is injected into the
die to generate the lost wax
pattern exerts the greatest
influence on final casting
dimensions, argues Dr Milan
Höracek.

Knowledge of the parameters
influencing dimensions throughout
the manufacturing process is indispens-
able when specifying pattern die dimen-
sions. These dimensions must embrace
all the subsequent dimensional changes
such that when the casting is completed
the dimensions required by the customer
are obtained within the tolerance fields
(see fig 1).

Investment casting technology can be
divided into four individual stages 9
(Table 1):

Stage 1 - die; final size
and obtainable accuracy/
tolerance are given by the
manufacturing process chosen;

Stage 2 - wax pattern;
practically the only possi-
bility of affecting result-
tant casting dimensions
through changing injec-
tion parameters during
wax pattern production.
(These problems are the
subject of this article).

Stage 3 - shell mould;
dimensional changes are
given by the type of
ceramic applied and by the
prescribed type of
drying and firing;

Stage 4 - pouring into
the shell mould; contraction of the foundry alloy
is given by its chemical
composition and the chosen
pouring temperature,
the optimum value of which
depends primarily on the size and shape of
casting and which must
be maintained within a
narrow range with a view
to possible appearance of
defects (mislun, shrinkages,
etc.).

Looking at the individ-
ual stages of the investment casting process,
we find that the position of the tolerance field (fig 1) can prac-
tically be affected only by the wax pattern,
namely by changing the input parameters dur-
ing its production (type of wax, injection para-

<table>
<thead>
<tr>
<th>OPERATION</th>
<th>EXAMPLE</th>
<th>Individual Influences</th>
<th>Total Influences</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. DIE MANUF.</td>
<td></td>
<td>(1,2,3a,3b,4)</td>
<td>(1+2+3a+3b+4)</td>
</tr>
<tr>
<td></td>
<td>100 mm</td>
<td>-0.02</td>
<td>+0.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-0.02</td>
<td>+0.02</td>
</tr>
<tr>
<td>2. WAX PATTERN</td>
<td></td>
<td>-0.1</td>
<td>+0.1</td>
</tr>
<tr>
<td></td>
<td>-1.2</td>
<td>+0.1</td>
<td>-1.2</td>
</tr>
<tr>
<td></td>
<td>-0.12</td>
<td>-0.12</td>
<td>-0.12</td>
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<tr>
<td></td>
<td>-1.08</td>
<td>-1.08</td>
<td>-1.08</td>
</tr>
<tr>
<td>3a. SHELL DRYING</td>
<td></td>
<td>-0.1</td>
<td>+0.1</td>
</tr>
<tr>
<td></td>
<td>+0.3</td>
<td>+0.1</td>
<td>+0.3</td>
</tr>
<tr>
<td></td>
<td>-0.22</td>
<td>-0.9</td>
<td>-0.22</td>
</tr>
<tr>
<td></td>
<td>-1.12</td>
<td>-0.68</td>
<td>-1.12</td>
</tr>
<tr>
<td></td>
<td>-1.08</td>
<td>-1.08</td>
<td>-1.08</td>
</tr>
<tr>
<td>3b. SHELL FIRING</td>
<td></td>
<td>-0.1</td>
<td>+0.1</td>
</tr>
<tr>
<td></td>
<td>+0.7</td>
<td>+0.1</td>
<td>+0.7</td>
</tr>
<tr>
<td></td>
<td>-0.32</td>
<td>-0.2</td>
<td>-0.32</td>
</tr>
<tr>
<td></td>
<td>-0.52</td>
<td>-0.52</td>
<td>-0.52</td>
</tr>
<tr>
<td></td>
<td>+0.122</td>
<td>+0.122</td>
<td>+0.122</td>
</tr>
<tr>
<td>4. METAL POURING</td>
<td></td>
<td>-0.1</td>
<td>+0.1</td>
</tr>
<tr>
<td></td>
<td>-1.5</td>
<td>+0.1</td>
<td>-1.5</td>
</tr>
<tr>
<td></td>
<td>-0.42</td>
<td>-1.7</td>
<td>-0.42</td>
</tr>
<tr>
<td></td>
<td>-2.12</td>
<td>-1.2</td>
<td>-2.12</td>
</tr>
<tr>
<td></td>
<td>-1.28</td>
<td>-1.28</td>
<td>-1.28</td>
</tr>
</tbody>
</table>

Table 1. Influences on the
final casting's dimensions.

Dimensional accuracy
of wax patterns

The resultant size and
capability of meeting the tolerance values of
a wax pattern are affected by three basic
factors:

- Type of pattern material (wax) used;
- Shape and size of component;
- Wax pattern manufacturing process
  (injection parameters).

Effect of pattern wax

The structure or the

Fig 1. Influence of individual
phases of investment casting
process to the final
dimension of casting.

This paper is adapted from the presentations by Dr Milan Höracek at the 33rd BICTA Conference, Cambridge in June 1997 and at the World Conference on Investment Casting, San Francisco in October 1996. It is published here with kind permission. Dr Höracek is with the Technical University Brno, Czech Republic.
tude of the effect of individual pattern material components on the resultant contraction makes it possible to prepare mixtures with a comparatively accurately defined final contraction.

Effect of shape and size of component
It is common knowledge that the magnitude of linear contraction of wax must be taken as orientation data (the same as for the alloy poured); the actual contraction values in individual basic planes (length, width, height) eventually depending on the shape and size of component, and also on the gating system. It can generally be said that the resultant wax pattern dimensions will depend on the course of wax pattern cooling in the die. This cooling is controlled by the distribution of temperature gradient in the wax pattern die system.

Effect of the wax pattern manufacturing process
As the majority of wax patterns are produced on injection presses, the term 'manufacturing process' refers here to how wax is conveyed into the die cavity, and especially to the injection parameters, among which the following are of great importance: (fig 2)
- temperature of injected wax;
- temperature of pattern die (initial temperature + method of cooling in the course of solidification and cooling of wax);
- wax injection pressure;
- wax flow rate (speed of filling the die-cavity);
- packing time (nozzle is open even when die cavity has been filled);
- holding time (from completion of packing phase until the die opening).

Due to press design, the above parameters, which constitute the injection cycle of the injection press cannot be con-
INVESTMENT CASTING

Fig 4c. Graphical representation of fig 4b.

A survey of experiments made, ie the choice of variable parameters whose effect on resultant contraction have been examined, can be found in Table 2. Each measurement was made 10 times under identical conditions. Two types of waxes were used:

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Filler</th>
<th>Melting</th>
<th>Curing</th>
</tr>
</thead>
<tbody>
<tr>
<td>B 417</td>
<td>38% Pasty</td>
<td>75°C</td>
<td>61°C</td>
</tr>
<tr>
<td>CK7/E</td>
<td>9-11% Water</td>
<td>84-86°C</td>
<td>72-76°C</td>
</tr>
</tbody>
</table>

Measured results
The combined influence of the most important parameters in the course of injection ie injection time (filling time

The effect of injection parameters on final wax pattern dimensions was investigated eg by Williams et al.

The authors followed the effect of basic parameters (injection time, injection rate and pressure) on the magnitude of final contraction. The effect of the above parameters on the final magnitude of contraction was proved and thus also their effect on a possible shift in the tolerance zone of resultant castings.

The initial conclusions of the authors (ie the manner in which individual factors are likely to affect contraction), have been rewritten and summarised in fig 3. It is evident from Fig 3 that the dominant effect was the injection time while the effects of injection pressure and rate were less pronounced. The authors, however, give in their work an example of an actual casting, whereby in the case of rejects due to dimensions (outside the
tolerance range prescribed by the customer) an improvement was brought about by shifting the tolerance range of the wax pattern by changing the injection parameters, without interfering with the pattern die dimensions.

Description of experiments
To observe dimensional changes a test specimen was used as given in fig 4a, on which the characteristic dimensions in three mutually perpendicular planes (l-length, h-height, w-width) were measured.

For measuring, a micrometer was used with an accuracy of 0.01mm. The time between the completion of wax pattern and the measurement itself was always at least 24 hours and at most 48 hours.

The examples of measured and calculated contractions are given in fig 4b.

All results (data obtained) were then plotted into graphs - see an example in fig 4c.
<table>
<thead>
<tr>
<th>TYPE OF INJECTION MACHINE</th>
<th>WAX TYPE</th>
<th>( T ) INJECTION TEMPERATURE (^{\circ})C</th>
<th>( P ) INJECTION PRESSURE [MPa]</th>
<th>INJECTION SPEED - WAX FLOW RATE</th>
<th>( T ) INJECTION TIME [s]</th>
<th>SIZE OF GATE CHoke [( mm )]</th>
<th>TOTAL Nr. OF EXPERIMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRYANT</td>
<td>B 417 filled wax</td>
<td>66</td>
<td>72</td>
<td>2 KONST. (4.1)</td>
<td>15 s, 30 s, 45 s</td>
<td>min - 14 mm(^2) + max - 39 mm(^2)</td>
<td>120</td>
</tr>
<tr>
<td>JENNY PRESS</td>
<td>B 417</td>
<td>54</td>
<td>60</td>
<td>2 non - measurable</td>
<td>15 s, 30 s, 45 s</td>
<td>min - 14 mm(^2) + max - 39 mm(^2)</td>
<td>120</td>
</tr>
<tr>
<td>SHELL-O-MATIC</td>
<td>CK7/E emulsified wax</td>
<td>60</td>
<td>62</td>
<td>3.4 min A0</td>
<td>35 s, 50 s, 65 s, 80 s</td>
<td>min - 14 mm(^2) + max - 39 mm(^2)</td>
<td>510</td>
</tr>
</tbody>
</table>

**Table 2: Summary of experiments - variables.**

426 and packing time) and the temperature of injected wax (measured in the nozzle) was measured using different presses including Shell-O-Matic, Bryant and Jenny Press.

**Evaluation of results**

**Effect of injection time**

Increasing the injection time (i.e. the sum of filling time and packing time = time when the nozzle is open) clearly indicate that there is a reduction in the overall value of contraction.

CK/E wax - increased injection time from 35 to 80 sec leads to the drop of contraction by approximately 0.2% (Fig 5). It should be noted that the initial period of increased time equals a higher contraction drop.

Similar tendencies could also be seen with wax B 417 (especially when using the higher wax temperature range of 66 - 72\(^{\circ}\)C). The higher the wax temperature the higher the influence of injection time.

Conversely, when wax temperature was low the influence of injection time was found to be less pronounced (only a...
slight drop in the contraction was observed with longer injection time, when temperature of wax was only 54°C).

Effect of wax temperature
Wax CK7/E - According to theoretical presumptions, the higher the wax temperature the higher the contraction (Fig 5). Simultaneously the influence of injection time was not observed. Clearly there was the same difference in contraction values (~ 0.2 %) in the examined range of wax temperatures (60-65°C) during different injection times.

Wax B417 - In the measured wax temperature ranges there were little or no differences in contraction values especially when injection time was higher.

Effect of injection pressure
After a deeper evaluation of the results, it can be generally stated that, with increasing pressure, there is less wax contraction (Fig 6). The value could be comparable with the influence of injection time to 6.8 MPa. It can be seen that with a lower injection time a higher rate of contraction will occur - Fig 6A (injection time 35sec) and Fig 6B (injection time 80sec).

Conclusion
When evaluating all factors influencing the final wax contraction it is necessary to consider all factors together as they act simultaneously and also effect one another. Fig 7 shows 'achievable' changes in contraction values when combining the above mentioned factors (injection time, injection pressure, wax temperature).

Different cooling rates due to the gating system design have an influence on the final wax contraction and the influence of the injection time can be observed.

The explanation of general tendencies in wax pattern contraction being affected by injection parameters could be as follows: The greater the volume of wax 'packed' into the die cavity, the lower the value of contraction (similar to the feeding technique in risers). The most 'effective packing period' is that just after filling the die cavity (ie the initial part of the 'packing time').

REFERENCES