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Measurement and Control of Pressure Inside Rotational Moulds

It has been known for many years[1-6] that a small positive pressure inside a mould during rotational moulding can have beneficial effects on the quality and properties of the moulded part. The potential benefits include the removal of bubbles ('pin holes') from the surface and the interior of the wall of the moulded part, as well as improved impact properties. However, it has only been possible to quantify the effects in the research laboratory due to the difficulty of measuring pressure inside moulds during commercial production. That situation is now changing due to the sophisticated nature of the 'Leonardo' types of rotational moulding machines. This paper reports on moulding cycles in which both the temperature and pressure were measured during the manufacture of polyethylene parts on a Leonardo rotomoulding machine. It is shown that the predicted effects are achieved and that control of the pressure inside a mould during rotational moulding is just as important as controlling the temperature inside the mould.

Introduction

During conventional rotational moulding it is normal to have a vent in the mould. Its purpose is to ensure that there is no pressure build-up inside the mould. If there was no vent then as the trapped air inside the mould has its temperature raised it has a tendency to expand. However, as the air is in the confined (fixed) space inside the mould, this leads to a build-up of pressure inside the mould. In the early days of rotational moulding it was considered undesirable to have a pressure build-up inside the mould because, particularly on large moulds, this could cause large opening forces on the mould clamps and perhaps blow the mould open.

Using the standard laws of physics it is relatively easy to show that the pressure (P) inside a rotational mold is directly related to the increase in temperature (T). That is: $P_2 = P_1 \times (T_2/T_1)$.

Where P_1 is the initial atmospheric pressure inside the mould at room temperature T_1, and P_2 is the new pressure as a result of the temperature increase from T_1 to T_2. When using this equation to calculate the pressure inside the mould, the temperatures T_1 and T_2 must be in degrees Kelvin ie (°C + 273).

During normal rotational moulding when a mould is heated from, say, 40°C to 200°C it would be expected that the pressure inside the mould would increase to (200+273)/(40+273) times atmospheric pressure, that is $1.51P_1$ (ie about 50% above atmospheric pressure).

Moulding Trials

The moulding trials reported here were

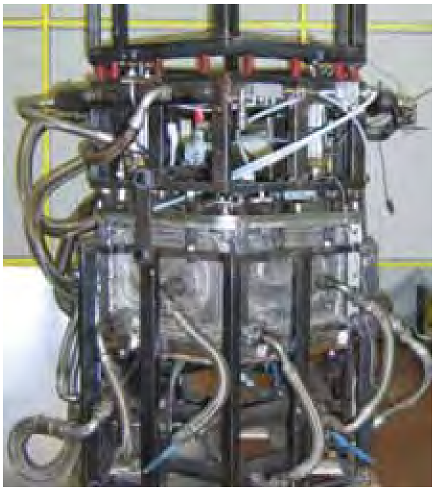

Figure 1: Mould (on left) with pipework to distribute heating and cooling fluid, and moulded part (on right).

carried out on a Leonardo machine Type TOP 1200x1500 using Linear Low Density Polyethylene with MFI 4.5 supplied by ICO Polymers. The moulding conditions were typical of those used during commercial rotational moulding. The mould and moulded part are shown in Figure 1. The mould was made from machined aluminium with general dimensions of 600 x 600 x 300 mm (approximately 100 litres capacity) and a general wall thickness of 10 mm.

As shown in Figure 1, the mould is directly heated/cooled by the flow of hot/cold oil through channels that are within the wall thickness of the mould. This ensures very uniform heat distribution all over the mould surfaces. On a Leonardo rotomoulding machine the temperatures of the mould, and the air inside the mould, can be monitored and controlled throughout the moulding cycle.

In all of the moulding trials reported in this paper the temperature and pressure inside the mould were monitored continuously. After moulding, the bubbles through the thickness were observed using a USB 20x digital microscope and the impact strength of test pieces cut from the mouldings was measured using the standard ARM falling weight impact test.

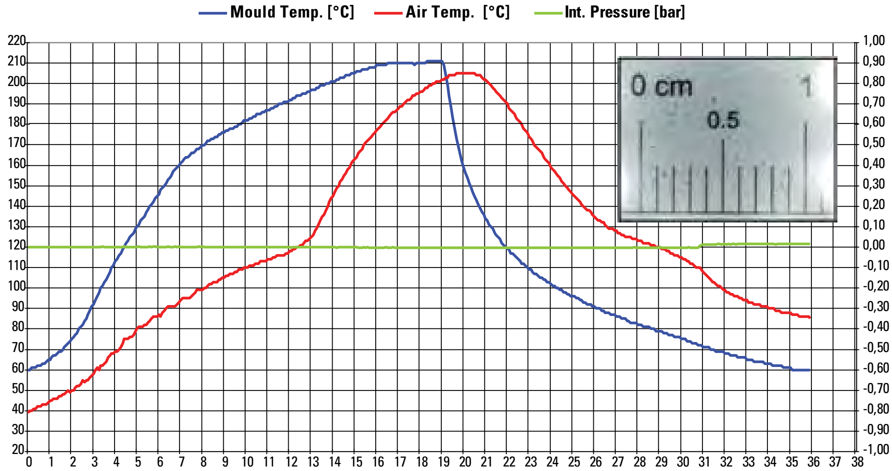

Figure 2: Vent Open - Variations of Mould and Internal Air Temperatures, and Internal Pressure for PIAT of 205°C.

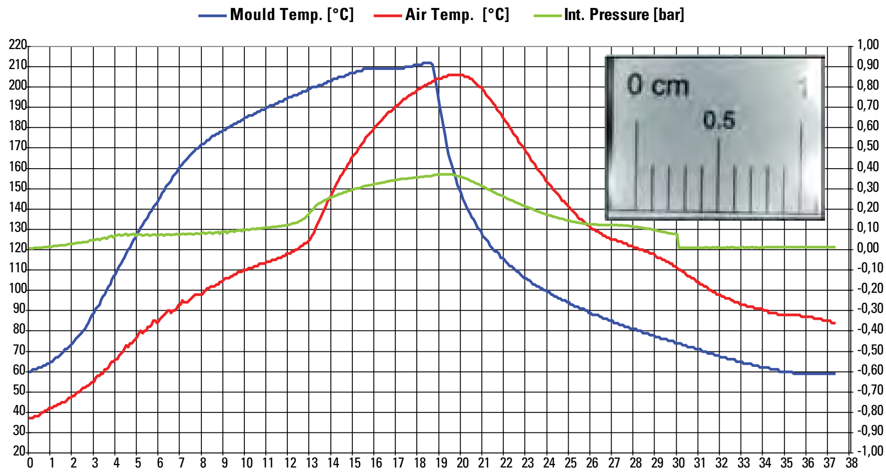

Figure 3: Vent Closed - Variations of Mould and Internal Air Temperatures, and Internal Pressure for PIAT of 206°C.

Results

In the first series of moulding trials the vent was open in the normal way and the Peak Internal Air Temperature (PIAT) was taken to 205°C. Figure 2 illustrates the temperature of the mould and the temperature of the air inside the mould. It also shows that the pressure does not build up inside the mould – it remains constant at atmospheric pressure throughout the cycle. The inset photograph shows the bubbles ('pin holes') on the surface of the moulding. It has been found generally that when there are bubbles or pinholes on the surface of a moulding then there are also bubbles and pinholes within the wall thickness of the moulding. Also, when the bubbles are removed from the surface they are also removed from within the wall thickness of the mouldings. This was confirmed by microscopic observations of the wall thickness of all the mouldings produced in these trials.

The impact strength of the mouldings in the first series of trials was measured using the standard ARM Falling Weight Test and the average impact strength was found to be 100.6 ft lbs. It should be noted that the value of the impact strength is not a number that can be used in design calculations. It is simply a basis for comparison with other test pieces taken from mouldings of the same shape and tested in the same way.

In the second series of trials the vent was closed from the beginning of the cycle and the Peak Internal Air Temperature (PIAT) was taken to 205°C (approximately). Figure 3 illustrates the temperature of the mould and the temperature of the air inside the mould. It also shows that the pressure of the air inside the mould increases in the predicted way, ie in proportion to the temperature increase.

When the PIAT reaches 205°C the magnitude of the pressure inside the mould is about 1.4 times atmospheric pressure (ie about 40% above atmospheric pressure). This is less than the theory predicts (ie 1.51 times atmospheric pressure). This may be because the mould expands as it is heated (this expansion is ignored in the theoretical calculation), and also there may be some leakage of air from the mould parting line during the heating phase. The latter effect is known to be very small on the high quality moulds used on the Leonardo machine. In trials when the temperature inside the mould was allowed to return to room temperature, the pressure inside the mould returned to atmospheric pressure (ie zero on the graph) or very slightly below zero. If there was air lost from inside the mould during heating then it would be expected that, on cooling, the pressure inside the moulding would go below zero (ie partial vacuum) because it is not possible to replace the air lost from inside the moulding.

Another factor that may contribute to the differences between the measured

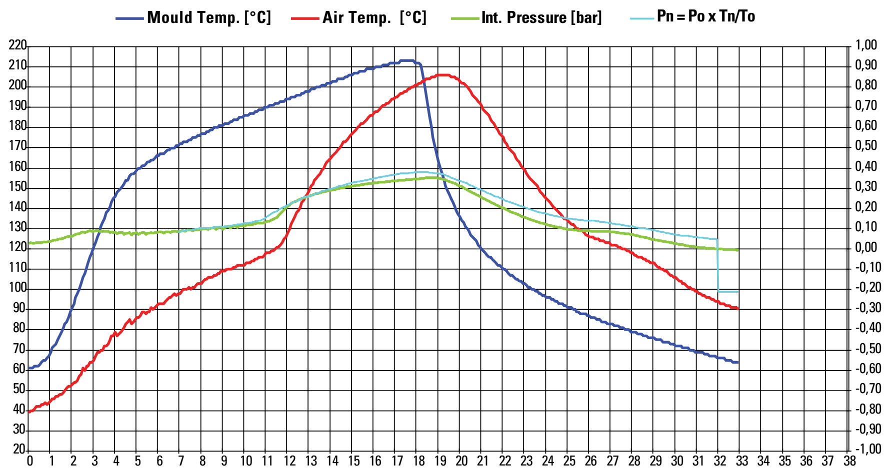

Figure 4: Calculated Internal Pressure (light blue line) Superimposed on the Measured Internal Pressure (light green line) and the Internal Air Temperature Trace (red line).

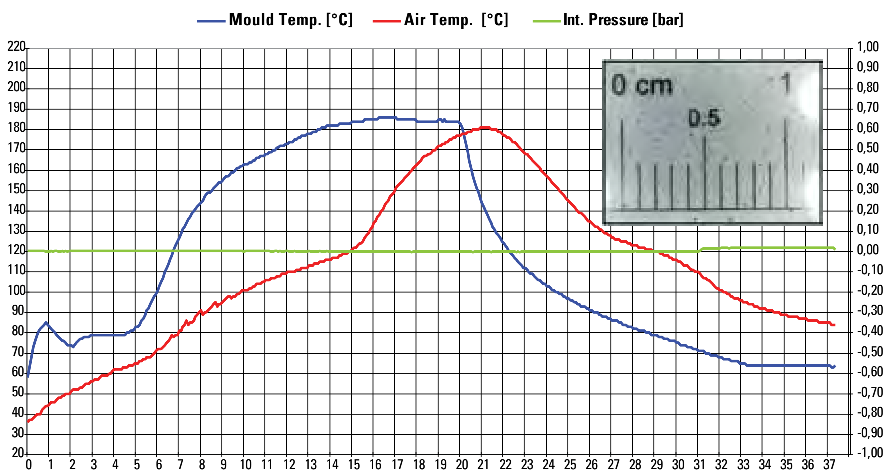

Figure 5: Vent Open - Variations of Mould and Internal Air Temperatures, and Internal Pressure for nominal PIAT of 181°C.

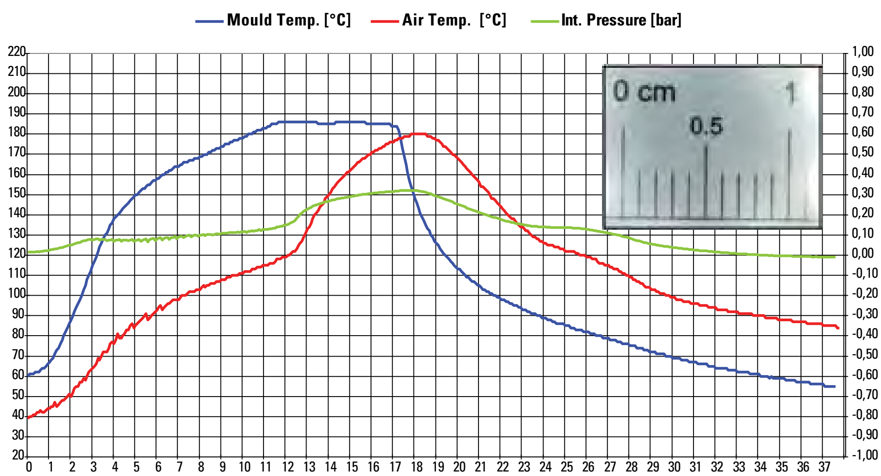

Figure 6: Vent Closed - Variations of Mould and Internal Air Temperatures, and Internal Pressure for nominal PIAT of 181°C.

and theoretical pressure in the mould is that the atmosphere inside the mould is not homogeneous in regard to temperature. The internal air temperature measurements shown in the graphs reflect the specific temperature at the point where the thermocouple probe measures the temperature. The temperature at other points inside the mould will be different. For example, the temperature close to the mould wall will be higher, and the temperature at the centre of the mould will be lower. On the other hand, the pressure measured inside the mould will reflect an average of the conditions inside the mould.

Figure 4 shows the internal pressure trace superimposed on the temperature trace and it is evident that the theory is correct in that the internal mould pressure is directly related to the internal air temperature. It should be noted that the calculated pressure value is obtained using a "delayed" value of the internal temperature. That is, to calculate the pressure at time "n", the temperature at time "n + 1" minute is used. This is because the thermocouple probe introduces a time delay of about 1 minute for the temperature measurement relative to the pressure measurement.

Also, in order to superimpose the temperature and pressure graphs, the reference conditions (P_1 and T_1) used as time zero in the formula ($P_2 = P_1 \times T_2/T_1$) were taken as the point where the mould was at 170°C and internal temperature was 100°C (minute 7): This was done on the basis that it is at this point that the mould becomes truly air tight due to first fused (and sintered) layer of PE covering the internal mould surface.

Referring back to Figure 3, it is interesting to observe the inset photograph. It shows that, as predicted, the build-up of pressure inside the mould has removed the bubbles from the surface of the moulding (and also from within the wall of the moulding). Therefore the surface quality and internal wall thickness are better as a result of the pressure build-up inside the mould.

Also, the impact strength of the moulding was 117.5 ft lbs which demonstrates a general trend that was observed – that is, the impact strength with the closed vent is better than when the same PIAT was used but the vent was open (100.6 ft lbs). Therefore, when the pressure builds up inside the mould not only is the aesthetic quality of the moulded part improved but its impact strength is better as well.

In Figure 5 the vent is open throughout the cycle and the PIAT is 180°C instead of 200°C. It is seen that that there is no pressure build-up inside the mould and that the bubbles within the wall are greater in number compared with the PIAT of 200°C.

In Figure 6 the PIAT is once again taken to 180°C but the vent is now closed throughout the cycle. It may be seen that the maximum internal pressure reaches about 1.32 times atmospheric pressure when the PIAT reaches 180°C. The pressure goes slightly negative (about -0.016 bar) when the internal air temperature cools to about 71°C. This may be because a small amount of air escaped from the mould (at the parting line or through the 'closed' vent) during the heating phase and has been unable to re-enter the interior of the moulding during cooling, or it could be related to other effects discussed above.

An interesting observation is that the inset photo in Figure 6 shows that as in previous cases where the pressure builds up inside the mould, the bubbles and pin-holes have been removed from the moulding. This means that a lower PIAT can be used (ie 180°C instead of 200°C), which results in faster cycle times and less degradation of the plastic moulding. The impact strength of the mouldings with PIAT = 200°C, with the vent open, was typically 100.6 ft lbs whereas with the PIAT = 180°C, with the vent open, the impact strength was generally about 87 ft lbs. However, with the PIAT = 180°C, and the vent closed, the impact strength was generally about 116 ft lbs, which compares favourably with the PIAT = 200°C, and the vent closed, where the impact strength was 117.5 ft lbs.

Figure 7 shows that with the vent closed and a PIAT of 163°C it is possible to get a good quality moulding in terms of removing the bubbles and pin holes. Under normal rotomoulding (with the vent open) it is necessary to wait for the time-temperature combination to remove the bubbles. This usually requires a PIAT of at least 200°C with the associated longer cycle time. The impact strength of the moulding with the PIAT of 163°C (and the vent closed) was 102.7 ft lbs . This is better than the impact values of 100.6 ft lbs and 87 ft lbs at PIATs of 200°C (vent open) and 180°C (vent open) respectively.

It should of course be noted that it is not advisable to use a PIAT, which is too low (even with internal pressure) because there are time-temperature issues related to getting good consolidation of the structure of the molten polyethylene. It can be seen,

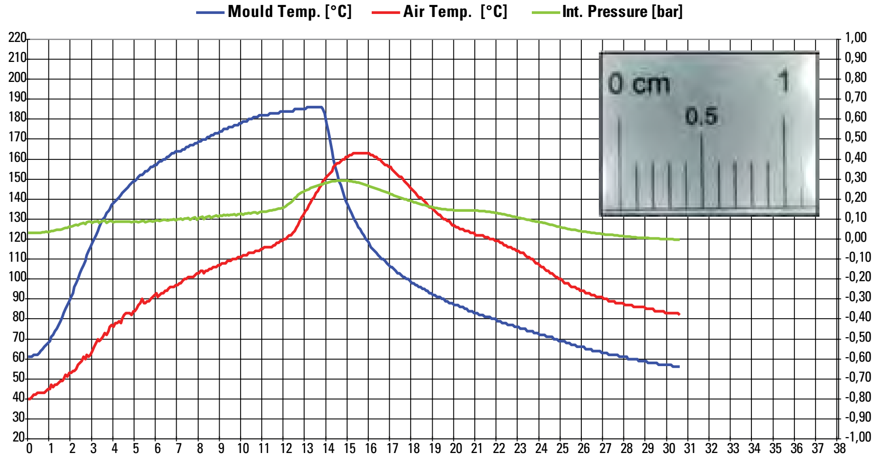

Figure 7: Vent Closed - Variations of Mould and Internal Air Temperatures, and Internal Pressure for nominal PIAT of 163°C.

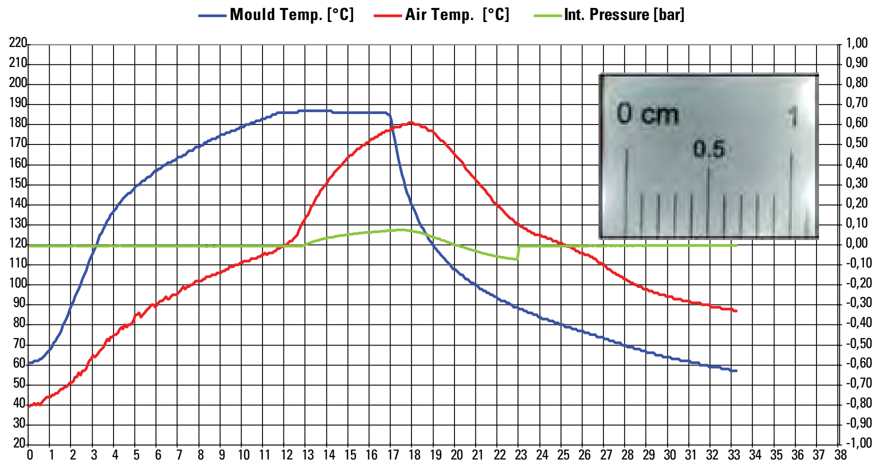

Figure 8: Vent Closed at 130°C - Variations of Mould and Internal Air Temperatures, and Internal Pressure for nominal PIAT of 180°C.

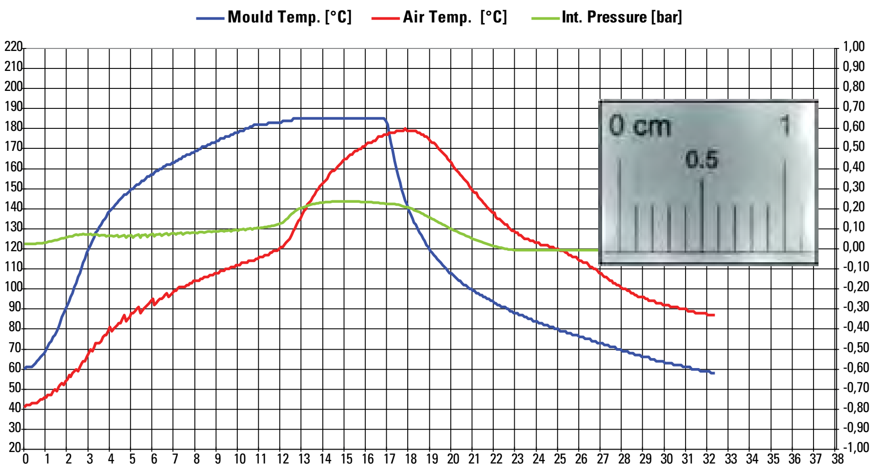

Figure 9: Moulding with a PIAT of 180°C and a Supavent (Type RJ1) fitted.

however, that the impact strength at 163°C (with the modest internal pressure of about 30% above atmospheric pressure) is very close to that of a moulding produced using a PIAT of 200°C and open venting, and of course the saving in cycle time with the 163°C PIAT can be very significant.

Another approach to utilizing modest internal pressure to remove bubbles, reduce cycle times and improve impact strength is to close the vent part way through the heating cycle. That is, instead of closing the vent from the beginning of the cycle, as shown in Figure 8, the vent

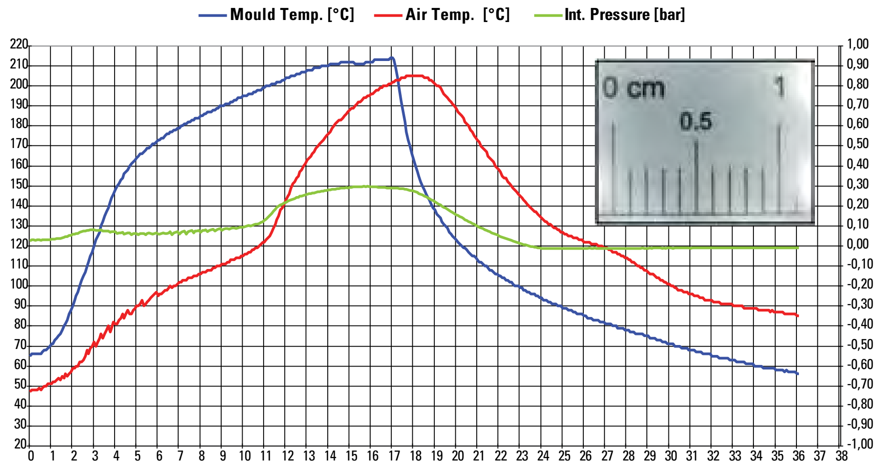

Figure 10: Moulding with a PIAT of 205°C and a Supavent (Type RJ1) fitted.

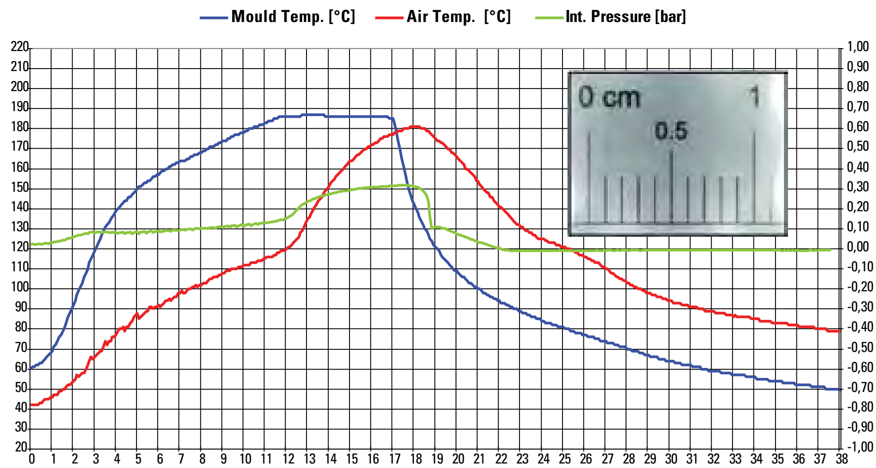

Figure 11: Moulding with a PIAT of 181°C and a Supavent (Type RJ1) fitted.

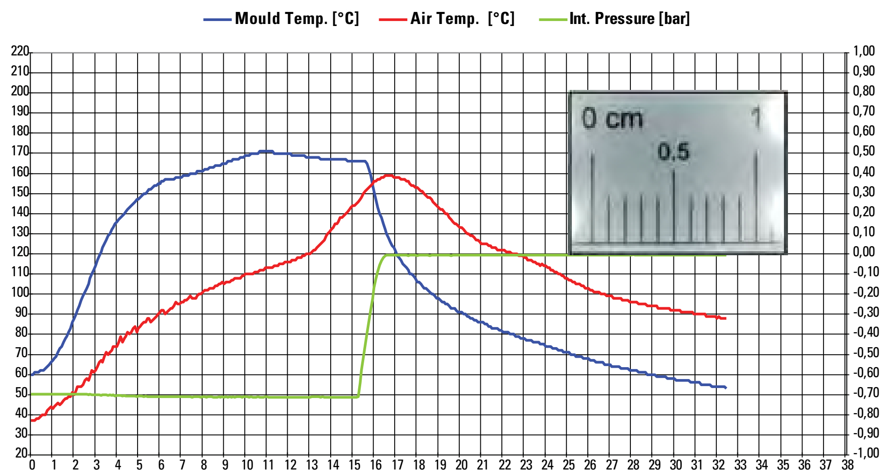

Figure 12: Moulding with a PIAT of 160°C using internal vacuum up to an internal temperature of 145°C.

can be open at the beginning of the cycle so that (initially) there is no pressure build-up. Then at an internal air temperature of 130°C (say) the vent is closed. It may be seen in Figure 8 that the pressure starts to build up as soon as the vent is closed. It reaches about 8% above atmospheric pressure by the time that the PIAT of 180°C is reached. It can be seen in Figure 6 that for a PIAT of 180°C with the vent closed throughout the cycle, the internal pressure reached a value of about 31% higher than atmospheric pressure.

The inset photograph on Figure 8 shows that, although the internal mould pressure build-up was only about a quarter of that when the vent was closed throughout the cycle, the bubbles have still been removed by closing the vent at 130°C - just as they were when the vent was closed at the beginning of the cycle. The impact strength of the moulding produced with PIAT= 180°C and closing the vent at 130°C was 95.1 ft lbs, which is better than the impact strength of 87 ft lbs achieved by a 'normal' moulding when the PIAT = 180°C and the vent is open throughout the cycle.

In recent years various types of 'automatic' vents have been introduced to the rotational moulding industry. Figure 9 illustrates the effect of using a SupaVent (type RJ1)[7]. This vent comprises a closed-ended silicone 'test tube' which replaces the traditional 'open tube' vent. An advantage of this type of vent is that the silicone tube prevents powder from being lost through the vent as the mould rotates. The SupaVent has a longitudinal slit that can open to allow venting at strategic points during the moulding cycle. It may be seen in Figure 9 that with a PIAT of 179°C the internal pressure builds up in proportion to the increase of internal air temperature inside the mould. The internal pressure attained is about 1.23 times atmospheric pressure – less than in the test where there was no vent (ie 1.31 bar in Figure 6).

During the heating period it appears that the silicone tube is compressed so that the mould is sealed (ie no venting). However the level of pressure build-up is less than having no venting so it is evident that some air has escaped through the vent slit during the heating period. It is also apparent that this air re-enters through the vent during cooling because the internal pressure decreases to zero by the end of the cycle. If air had escaped from the mould and not had a chance to re-enter during cooling then the internal pressure would have become negative by the end of the cycle.

The inset photograph on Figure 9 shows that the bubbles and pin-holes are removed very effectively using the SupaVent. The impact strength of the mouldings using the SupaVent was 97.8 ft lbs. This is an improvement when compared with using a PIAT of 180°C (vent open) where the impact strength was 87 ft lbs, but it is not as good as having the vent closed throughout the cycle (116 ft lbs).

Figure 10 shows the results when the PIAT = 200°C and a SupaVent is used. The internal pressure builds up to 1.29 bar, which is less than occurs when the vent is closed throughout the cycle. As in earlier cases where the pressure increases inside the mould, the bubbles are removed. The mouldings with the SupaVent and a PIAT of 200°C had an impact strength of 113 ft lbs, which compares with impact strengths of 100.6 ft lbs at PIAT of 200°C (vent open) and 117.6 ft lbs at PIAT of 200°C (vent closed).

Generally all the tests with the SupaVents at a variety of different PIATs exhibited the type of behavior illustrated in Figures 9 and 10. That is, the increase in pressure inside the mould was somewhere between an open vent and a closed vent and the impact strength changed in proportion to the internal pressure. Generally the SupaVent produced a moulding with an impact strength better than an open vent but not as good as a closed vent.

It was also found that the pressure traces exhibited by the SupaVents depended on the batch of the SupaVents. In general they behaved as in Figures 9 and 10, but some SupaVents produced a pressure trace as shown in Figure 11. In this case there is a sudden drop in pressure inside the mould during cooling suggesting that the slit in the SupaVent has opened suddenly to allow air to enter the mould but then it has closed again for the remainder of the cooling period. Although the shape of the internal pressure graph is different in Figure 11, the benefits of the internal pressure are still achieved – removal of bubbles and an impact strength value of 108.8 ft lbs, which is between the values for an open vent (87 ft lbs) and closed vent (116 ft lbs) at the same PIAT of 180°C.

In the final series of tests the effects of moulding with a partial internal vacuum inside the mould was explored. Although this technique is seldom used commercially (due to the poor quality of the seal at the parting line in rotational moulds) it has been referred to in the literature[2-4,6] as an alternative means of achieving the benefits of putting pressure on the molten plastic.

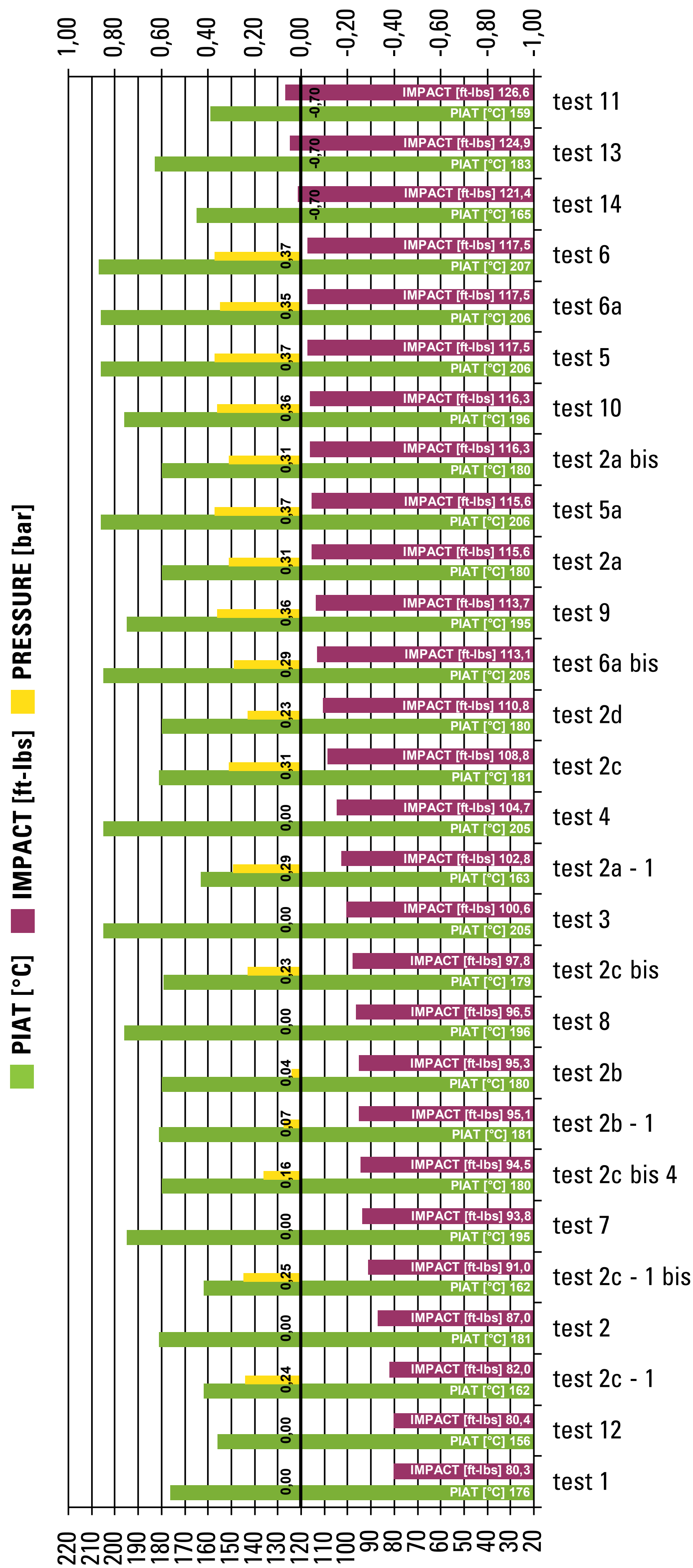

Figure 13: All test results in order of increasing Impact strength.

Test No.	Max. Temp Mould (°C)	Start of Cooling Time (minutes)	Internal Temp to Stop Heating (°C)	PIAT (°C)	Time to Melt (sec.)	Oil to Mould Heating Ramp (°C/min)	Final Oil Temp to Mould(°C)
test 1	182	18	170	176	840	20	190
test 2	186	19	175	181	900	40	190
test 2a	186	16,5	175	180	720	40	190
test 2a bis	186	16,5	175	180	720	40	190
test 2a - 1	186	13,5	150	163	720	40	190
test 2b	186	17	175	180	732	40	190
test 2b - 1	186	17	175	181	732	40	190
test 2c	186	16,5	175	181	726	40	190
test 2c bis	186	16,5	175	179	726	40	190
test 2c bis 4	186	16,5	175	180	726	40	190
test 2c - 1	186	16,5	150	162	726	40	190
test 2c - 1 bis	185	16,5	150	162	726	40	190
test 2d	186	16,7	176	180	708	40	190
test 3	210	18,5	200	205	750	20	230
test 4	210	18	200	205	690	40	230
test 5	210	18,2	200	206	750	20	230
test 5a	212	18	200	206	726	20	230
test 6	210	17,5	200	207	690	40	230
test 6a	212	18	200	206	690	40	230
test 6a bis	213	18	200	205	690	40	230
test 7	210	16	180	195	750	20	230
test 8	210	15,5	180	196	702	40	230
test 9	210	16	180	195	750	20	230
test 10	210	15,5	180	196	714	40	230
test 11	170	15,6	152	159	780	40	180
test 12	172	15,1	150	156	762	40	180
test 13	186	15	177	183	738	40	190
test 14	185	14,3	157	165	738	40	190

Table 1: Summary of all Test Conditions and Results.

Table 1 Continued on page 27

The use of partial vacuum overcomes concerns about pressure build-up inside the mould. Figure 12 illustrates what happens if the pressure inside the mould is reduced to -0.7 bar from the beginning of the cycle and then this partial vacuum is released just before the PIAT is reached. The pressure inside the mould returns to atmospheric pressure but the effect on the molten plastic is that a pressure of 1.7 bar has been applied to it. This very effectively removes the bubbles from the moulding and resulted in an impact strength of 126.6 ft lbs – the best result for any of the mouldings, and at the lowest PIAT of 160°C. A similar impact result was obtained when the vacuum technique was used with a PIAT of 180°C. Appendix 1 shows some earlier tests using a closed vent, or internal vacuum, during rotational moulding of a different grade of polyethylene. The benefits of using internal pressure, particularly the vacuum effect, are confirmed in these earlier tests.

The data obtained from all of the moulding trials is given in Table 1, and Figure 13 summarises all the results for PIAT, internal pressure and impact strength. In Figure 13 the results are presented in ascending order of impact strength. This shows that the level of the pressure inside the mould has a direct correlation with impact strength. An open vent (zero internal pressure) gives the lowest impact strength whereas the use of partial vacuum inside the mould (which creates the greatest pressure on the melt when it is released) gives the greatest impact strength. When the internal pressure is greater than 0.3bar then the level of the PIAT (in the range 160°C to 210°C) is not important – good impact properties (and bubble removal) can be achieved due to the pressurization effect on the melt, and this seems to override the temperature-time effects.

General Observations

The results in this paper represent an

Oil Temp Set in Heating Unit (°C)	Max. Internal Pressure (bar)	ARM Falling Weight Impact (ft-lbs)	MOULD VENT	Notes
225	0	80,25	OPEN	Start Internal cooling air flow at T int < 110°C
225	0	87	OPEN	Start Internal cooling air flow at T int < 110°C
225	0,31	115,6	CLOSED	Vent always closed
225	0,31	116,3	CLOSED	Vent always closed (same cycle as 2a)
225	0,294	102,75	CLOSED	Vent always closed
225	0,04	95,3	CLOSED	Vent: open then closed from T internal 150°C in heating up to 150°C in cooling then OPEN
225	0,074	95,1	CLOSED	Vent: open then closed from T internal 130°C in heating up to 130°C in cooling then OPEN
225	0,31	108,8	SUPAVENT	Supravent installed
225	0,23	97,8	SUPAVENT	Supavent installed (same cycle as 2c but lower pressure reached)
225	0,16	94,5	SUPAVENT	Supavent installed (same cycle as 2c but lower pressure reached)
225	0,238	82	SUPAVENT	Supavent installed
225	0,246	91	SUPAVENT	Supavent installed (same cycle as 2c-1 but higher pressure reached)
225	0,227	110,8	CLOSED	Vent closed with 0,5 mm spacers between mould flanges
240	0	100,6	OPEN	Start internal cooling air flow at T int < 110°C
240	0	104,7	OPEN	Start internal cooling air flow at T int < 110°C
240	0,37	117,5	CLOSED	Open vent and start internal cooling air at T int < 110°C
240	0,37	115,6	CLOSED	Vent always closed
240	0,37	117,5	CLOSED	Open vent and start internal cooling air at T int < 110°C
240	0,35	117,5	SUPAVENT	Supavent installed
240	0,29	113,1	SUPAVENT	Supavent installed (same cycle as 6a but lower pressure reached)
240	0	93,8	OPEN	Start internal cooling air flow at T int < 110°C
240	0	96,5	OPEN	Start internal cooling air flow at T int < 110°C
240	0,36	113,7	CLOSED	Open vent and start internal cooling air at T int < 110°C
240	0,36	116,3	CLOSED	Open vent and start internal cooling air at T int < 110°C
225	-0,7	126,6	VACUUM	Vent closed and vacuum (-0,7 bar) up to internal T > 145°C
225	0	80,4	OPEN	Vent always open
225	-0,7	124,9	VACUUM	Vent closed and vacuum (-0,7 bar) up to internal T > 175°C
225	-0,7	121,4	VACUUM	Vent closed and vacuum (-0,7 bar) up to internal T > 145°C

important breakthrough in rotational moulding. Several years ago a major step forward for the rotational moulding industry was the discovery that the temperature of the air inside the mould provided valuable information, which enabled close control over the rotational moulding cycle. Now it has been demonstrated that the pressure variations inside the mould provide equally useful information.

It has always been generally accepted in rotational moulding that a good quality open vent is needed so that there is no pressure increase inside the mould. The results reported in this paper demonstrate that if the pressure is monitored throughout the rotomoulding cycle then the effectiveness of the venting can be observed. This is very important because incorrect or inefficient venting will lead to undesirable effects inside the mould, which leads to major quality control problems such as warpage of the moulded product.

Perhaps more importantly it has been demonstrated in this report that controlling the pressure inside the mould can improve product quality and reduce cycle times. Just as it is now becoming very common to monitor, and control, the temperature inside the mould during the rotational moulding cycle, in the years to come it will be equally commonplace to monitor and control the pressure inside the mould. By monitoring the air pressure inside the mould future rotational moulding machines will be capable of 'active venting' rather than the 'passive venting' of the past, ie making changes to the internal air pressure inside the mould in real time so as to improve the quality of the rotomoulded part. It is shown in these trials that the use of a partial vacuum in the early part of the moulding cycle can be particularly effective in reducing cycle times, improving the aesthetic quality of the moulded part, and increasing the impact strength of the moulding.

It is also shown in this work that 'mechanical' automatic vents, such as the SupaVents, provide a mechanism by which powder can be stopped from exiting the mould during heating, and the internal pressure inside the mould can build up to remove pin-holes and improve impact performance of the moulded part.

As a final comment, it is very important to note that in all of the tests reported here the moulds are of very high quality (well sealed and well clamped) and the pressure generated inside the mould is very small. It is critically important for moulders to recognize that moulds and machines must be designed to accommodate the pressures generated inside the mould so that the benefits referred to in this paper are achieved in a safe manner.

On commercial molds and machines, and particularly machines such as the Leonardo that have very good quality molds, then pressure control is safe and straightforward. However, someone making their own molds could create safety problems for themselves so it is very important that we stress clearly that molds must be well made in order to get the benefits from internal mold pressure.

Conclusions

The rotational moulding trials reported in this paper demonstrate the following:

1. In a sealed mould, the pressure inside the mould varies in proportion to the air temperature variations in the mould.
2. Typically when the internal air temperature reaches a Peak Internal Air Temperature (PIAT) of 200°C, the internal pressure reaches a value which is about 40% higher than atmospheric pressure.
3. The pressure build-up inside a rotational mould can have a number of beneficial effects. These include (a) keeping the plastic in contact with the mould wall so that there is more effective cooling of the plastic part (b) the bubbles (or pin-holes) are removed rapidly from the moulded plastic (c) the cycle times can be reduced and (d) the impact strength of the moulded part is increased.
4. Up until an internal air pressure of about 0.3 bar the impact properties increase as the PIAT increases (until about 210°C). If the internal air pressure is greater than 0.3 bar then the impact strength is essentially independent of the PIAT (between values of 165°C and 205°C).
5. Using partial vacuum inside the mould during the heating phase of the rotomoulding cycle is a very effective way of achieving the benefits referred to under (3).
6. On the basis of the results reported in these trials, it is recommended that in rotational moulding machines of the future, both the internal air temperature and the internal air pressure should be measured and controlled.

References

1. Chen, C.H. et al, "Mold Pressurisation as a Method to Reduce Warpage in Rotational Molding of PE", Polym., Eng., Sci., 30, 23 (1990) pp 1523-1528.
2. Spence, A.J. and Crawford, R.J., "Mould Pressurisation removes Bubbles and Improves Quality of Rotationally Moulded Products", Rotation, Vol 4, Issue 2 (1995) pp 16-23.
3. Spence, A.J. and Crawford, R.J., "Simulated Bubble Removal Under Pressurised Rotational Moulding Conditions", Rotation, Vol 4, Issue 3 (1995) pp 17-23.
4. Spence, A.J. and Crawford, R.J., "Pin-holes and Bubbles in Rotationally Moulded Products", in *Rotational Moulding of Plastics*; 2nd edition, edited by R.J. Crawford, Research Studies Press (1996) pp 217-242.
5. Kearns, M and Crawford, R.J. Practical Guide to Rotational Moulding, 2nd Edition, RAPRA, Shawbury, Shrewsbury, (2012).
6. Bergamo, L., "Vacuum Rotomolding: No More Bubbles", RotoWorld, vol 7, Issue 5 (2011) pp 48-50.
7. For details about SupaVent see http://www.laplastecnica.co.nz/supavent.

Appendix 1 – Previous rotomoulding trials using ICO - Icorene 1613 BK85 black:

Test No.	Max. Temp Mould (°C)	PIAT (°C)	Max. Internal Pressure (bar)	ARM Falling Weight Impact Strength (ft-lbs)	Mould Vent	Notes
1613 BK85 / Test 1	211	194	0	97,5	Open	Vent open
1613 BK85 / Test 2	186	171	0	93,0	Open	Vent open
1613 BK85 / Test 3	185	172	0,31	122,8	Closed	Vent always closed
1613 BK85 / Test 4	186	172	-0,44	147,1	Vacuum	Vacuum
1613 BK85 / Test 5	185	171	-0,43	143,0	Vacuum	Vacuum
1613 BK85 / Test 6	186	171	-0,34	143,8	Vacuum	Vacuum


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