PRT-4 | 751

MILITARY TECHNICAL COLLEGE

CAIRO - EGYPT

Quantitative and Qualitative Evaluation of Shell Casting Surfaces

Dr. S.M. EL Fayoumi *

ABSTRACT

The shell casting process is the most suitable casting process for producing complicated components. The development in components quality will increase its potential. The processing may be regarded as a double casting process. This lead to error propagation during precessing. Therefore, sources of imperfection of the casting surface may result from one or more of the following:

1. The metalic mould used to produce the wax cast.
2. Solidefication characteristics of the wax material.
3. The procedure of shell prepartion.
4. Behaviour of the shell during pouring of metal and during solidification of melt.
5. Mode of solidication of the molten metal.

To investigate the process, some measurements were carried out on a three co-ordinate measuring machine for both wax mould and the casting component.

The dimensions of the plate considered were about 160x130x15 mm.

The study suggested two parameters to quantify the sink namely sink volume and the ratio between sink volume to its surface area. A computer graphics was used to construct iso-contour mapping of the sinks in such a way to visualize the sink. The total geometry of the component is throuroghly studied through the analysis of the three dimensional measurements. This mean of analysis and assessment is a helpful tool towards achieving casting design of high dimensional and geometrical qualities.

* Assistant Prof. , Production Eng.Dept. , Faculty of Eng. Alex.Univ.

INTRODUCTION

The shell moulding casting is a complicated process influenced by many variables. The surface quality of the product is mainly characterized by the sink The sink is first formed during wax mould then it is reproduced in the shell. The casted component possesses a sink which is the out-come of the shell mould and the mode of solidfication of melt in the shell. This work studies the final designs of dies producing the wax moulds, and the final products produced. The measurements of the moulds have been carried out using three co-ordinate measuring machine. The study can be applied efficiently in checking surfaces produced by NC machines [1,2,3]. The casting component should be so selected to reveal the characteristics of shell mould surface (Sinks). A component of a plate shape which possess a high surface to volume ratio will enhance the presence of sinks. This in turn will enable a through study of the surface quality. The design parameters of the dies and the working conditions will be sensitive with respect to the selected component. Fig. (1) shows the studied component, which is a plate of 160 x 130x 15 mm. with a matrix of prutreeding marks 6x4. The marks are hemisphers of 3 mm diameter.

These are located at equidistant apart. It was planned that the height of these marks will indicate proper assessment of surface quality. However this have proved to be unsuccessful, instead the mid points on the surface were measured. The mould gate is located at the middle of the thickness of the longer side of the plate Fig. (3).

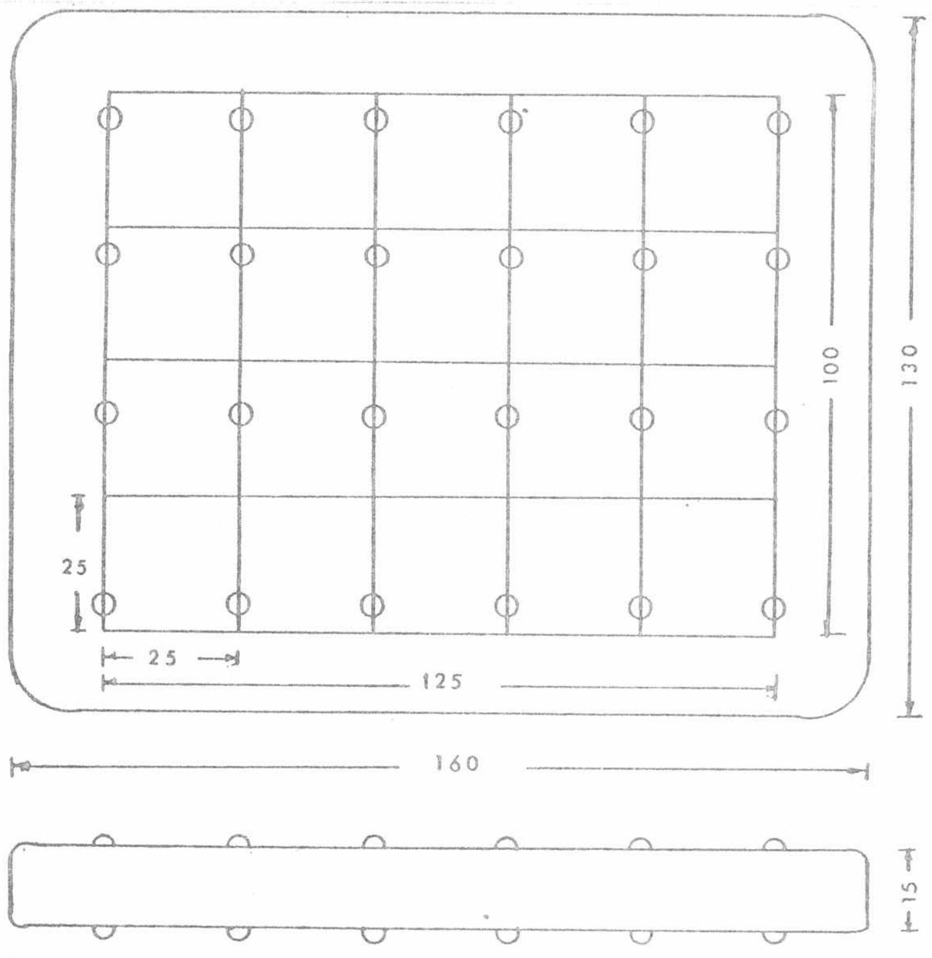


Fig. (1) Shell moulding casting component.

The study conducted to this component can be conducted to any form or any geometrical fcature.

MEASURING EQUIPMENT

The wax mould and casting component are measured using three co-ordinate measuring machine. The machine was Taly-check of Rank Taylor Hobson a self learning computerised machine. It is of 1µm resolution in the three axis and equiped with HP 85 microcomputer. Meanwhile, the machine is capable of collecting the required amount of data but the microcomputer system is not capable of analysing a special types of applications.

MEASUREMENTS

The method of probing the component in the three co-ordinate measurements is of utmost importance. This is reflected directly on the analysis and interpretation of the measurements. Thus, the measurements were carried out in such a way to investigate the total geometry of the components. The component is located in an up-right position Fig. (2), where the star probe can approach the component from two opposite directions. The direct-tion of probe movement is almost perpindicular to the component surface. The probe used in measurement is the star probe Renishow (touch trigger probe). Measurements, were collected from both sides of the component at the nodal point of the square grid. The grid was 125 x 100 mm Fig.(1) and the side of square is 25 mm. Since, two different stylii are being used during measurements. Measurements of both surfaces are belonging to two different co-ordinate system. In order to interrelate these

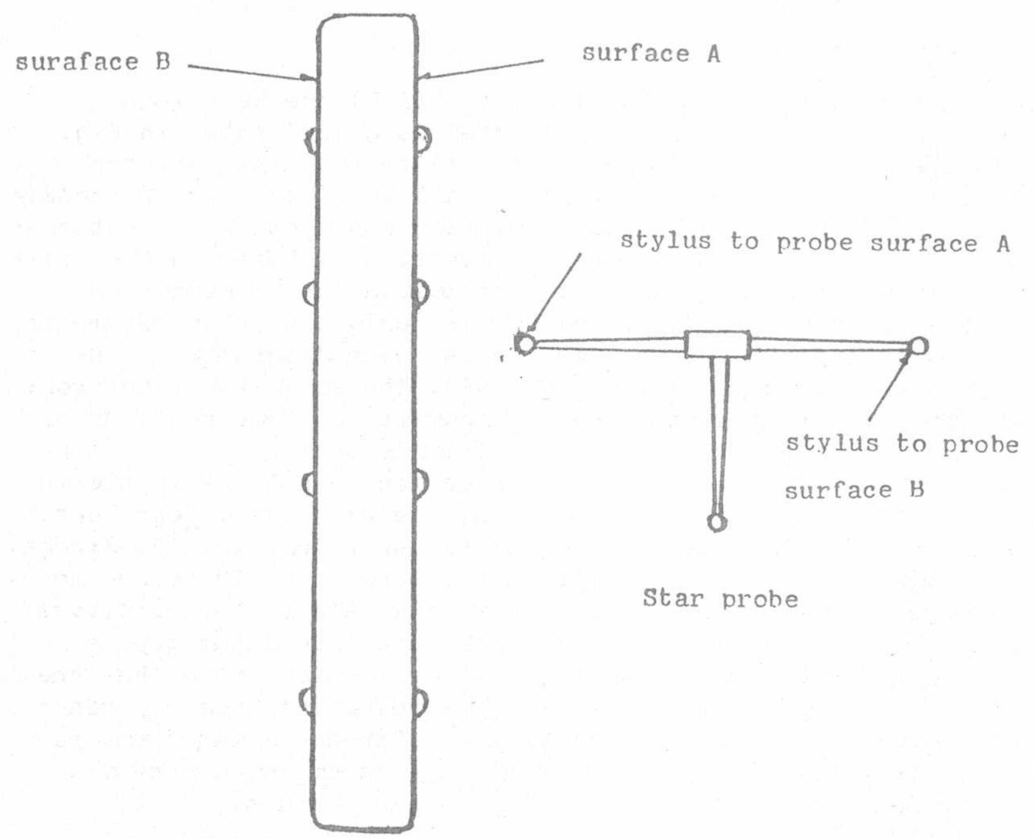


Fig. (2) Component location relative to probe.

systems together the co-ordinates of both sylii in relation to a physical target located on the machine (spherical surface or cube) were determined. Thus the relation between the two sets of the three measurements systems are related to each other as given in the following equations:

$$a = \alpha_2 - \alpha_1 \quad (1)$$

$$b = \beta_2 - \beta_1 \quad (2)$$

$$c = \gamma_2 - \gamma_1 \quad (3)$$

where :

α_1 , β_1 , γ_1 are the co-ordinates of the first slylii

α_2 , β_2 , γ_2 are the co-ordinates of teh second stylii

a , b , c are the origin of the measurements co-ordinates of surface B in relation of the co-ordinates of surface A.

Thus, the measurements of surface B can be related as given in the follwing equations:

$$x = x' - a \quad (4)$$

$$y = y' - b \quad (5)$$

$$z = z' - c \quad (6)$$

where:

x,y,z are the co-ordinates measurements of surface B refering to the same measurement system of surface A

x',y',z' are the cordinates measurements of surface B indepent of measurement system of surface A .

ANALYSIS OF MEASUREMENTS

The number of measured points on each surface (A,B) are 30 points. The locations of these points are distributed as a grid shown in Fig. (1). A reference datum is required to investigate the sink geometry (casting surface). The reference surface should be a stable reproducable surface from cast to cast. Such characteristics would be of a great help in the study. The proper datum reference selection is based on the solidus isotherm propagation mechanism. The solidifcation of either wax mould or casting component is governed by die design, working parameters and physical properties of molten. Fig. (3) shows a diagramatic line sketch of the die used in producing wax mould. The solidification front is dependent on the gating system and the geometry of component. After the die is complitely filled with wax the solidification front will be as indicated in Fig. (3). The rate of propagation of solidus isotherms is dependent on the superheat temperature of the wax, its latent heat, mould filling and rate of heat transfer to the surroundings. The direction of propagation is indicated in the same figures. The 18 points measured on the edge of casting surface are strongly related to solidification front and solidus isotherm. An adequate reference datum may be determined from these points. A hypothetical assumption state that the sink will be of an ideal homogeneous geometry resulting from a perfect steady working conditions. Consequently, the reference datum from the 18 points will be a flat surface. The reference datum is constructed by fitting the measurement data to the following equation.

$$z = ax + by + c \quad (7)$$

where:

x,y are the co-ordinates of points along teh casting surface z is the co-ordinate of points measured perpindicular to casting surface.

a,b,c are constants depends on the surface location.

In practice the ideal sink i.e unifom sink geometry does not exist due to lack of steadiness in the working conditions. Meanwhile, the 18 points should be screened in such a way to eliminate effect of sink geometry on

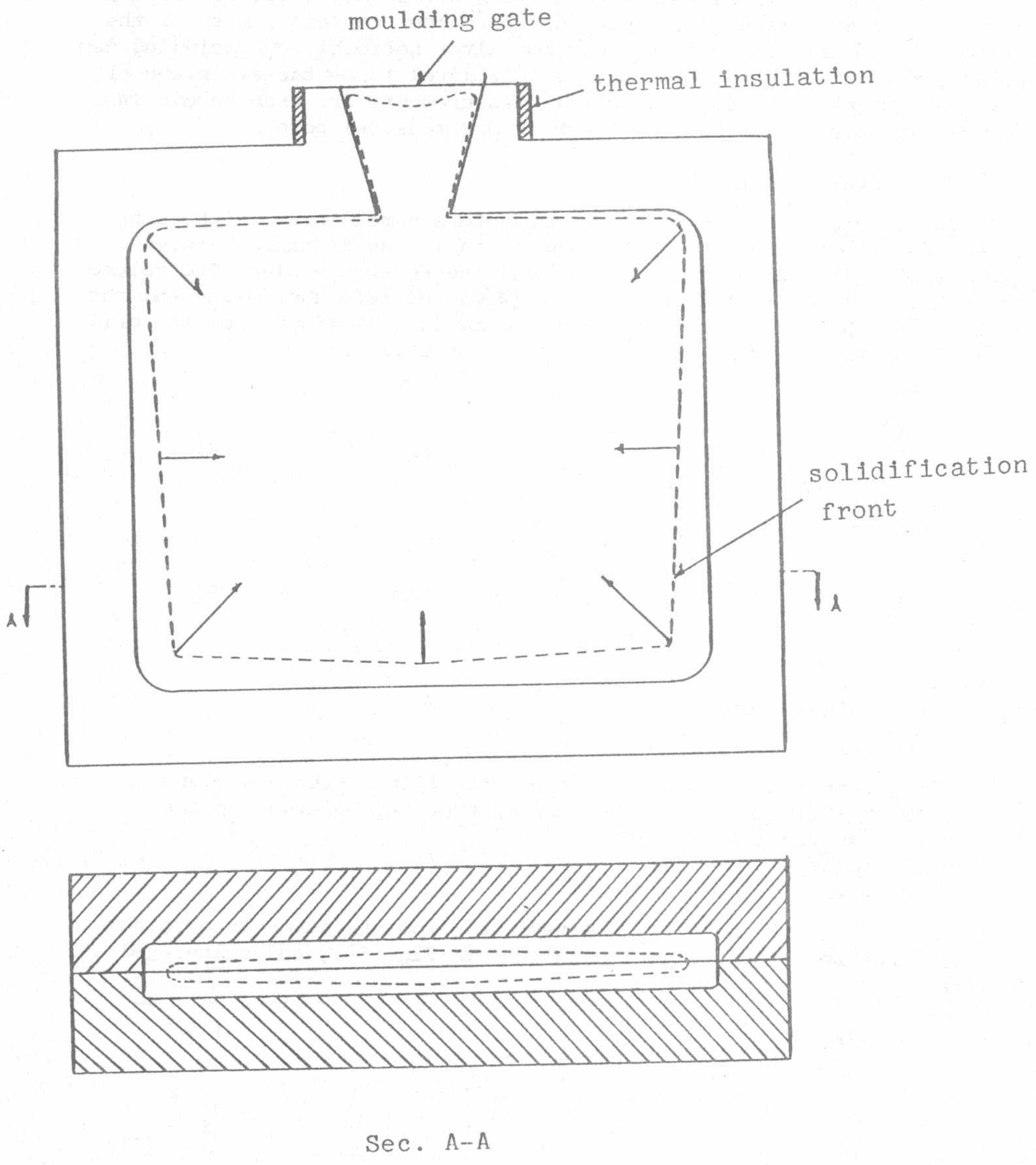


Fig. (3) Wax moulding die and solidification front.

the reference datum. This is achieved by excluding the point that possesses maximum deviation from the best fitted plane and then refitting the other 17 points. This sequence is repeated untill there is only 3 points which define the reference datum plane surface. The advantage of this treatment is that the final reference plane is perfectly free from any bias to sink geometrical form. If the solidification front and solidus isotherms posses large measurement points the suggested screening procedure will be impractical for its heavy compution time. The screening may be stopped when the deviation from the least square plane does not exceed a certain tolerated value, the coefficient of correlation approaches certain limits or the fitted plane direction cosines does not alter noticably by excluding new points. The reference datum plane is considered to be the X-Y plane of a new co-ordenate system to which all measurements are transfered. The z co-ordinate represent the sink depth at any measured point.

SINK ANESSEMENT

The sink is characterised by three parameters namely sink depth, sink volume and its surface area. The sink depth is the distance between the lowest point on the surface area and the reference plane The volume of the sink is the volumetric space between the reference plane and the surface area of the casting. The sink volume is determined from the grid elements shown in Fig. (4) and calculated as follows:

$$V_e = A'.H$$

$$A' = \tfrac{1}{2}\begin{vmatrix} x'_1 & y'_1 & 1 \\ x'_2 & Y_2 & 1 \\ x_3 & y_3 & 1 \end{vmatrix} \qquad (8)$$

$$H = \frac{z_1 + z_2 + z_3}{3}$$

$$V = \sum_{i=1}^{n} V_{ei} \qquad (9)$$

where :

V_e is the volume element.

A is the prism basa area.

x',y' are co-ordinates of the nodal points at the reference plane

z is the distance between component surface and reference plane

H is the average prism height

V is the total sink volume.

n is the number of sink elements .

The surface area of the sink is determined from the elements of sink surface area specified by grid nodal points Fig. (3), and calculated as follows:

$$A = \sum_{1=1}^{n} A_s \qquad (10)$$

$$A_3^2 = \tfrac{1}{4}\begin{vmatrix} y_1 & z_1 & 1 \\ y_2 & z_2 & 1 \\ y_3 & z_3 & 1 \end{vmatrix}^2 + \tfrac{1}{4}\begin{vmatrix} z_1 & x_1 & 1 \\ z_2 & x_2 & 1 \\ z_3 & x_3 & 1 \end{vmatrix}^2 + \tfrac{1}{4}\begin{vmatrix} x_3 & y_1 & 1 \\ x_2 & y_2 & 1 \\ x_3 & y_3 & 1 \end{vmatrix}^2 \qquad (11)$$

A is the total sink surface area

AS is the sink element surface area.

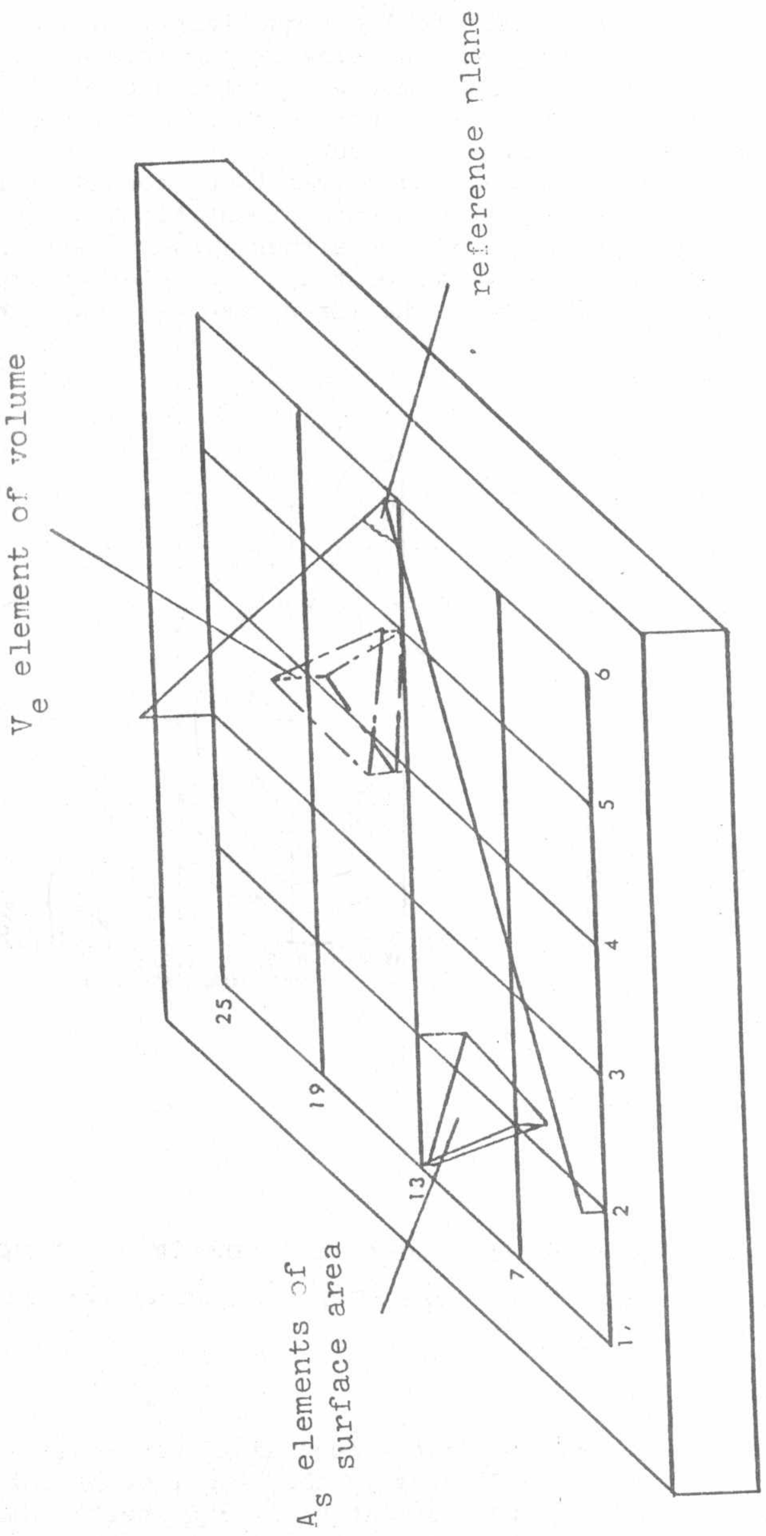


Fig. (4) Nomeclature of measurement grid and elements of sink.

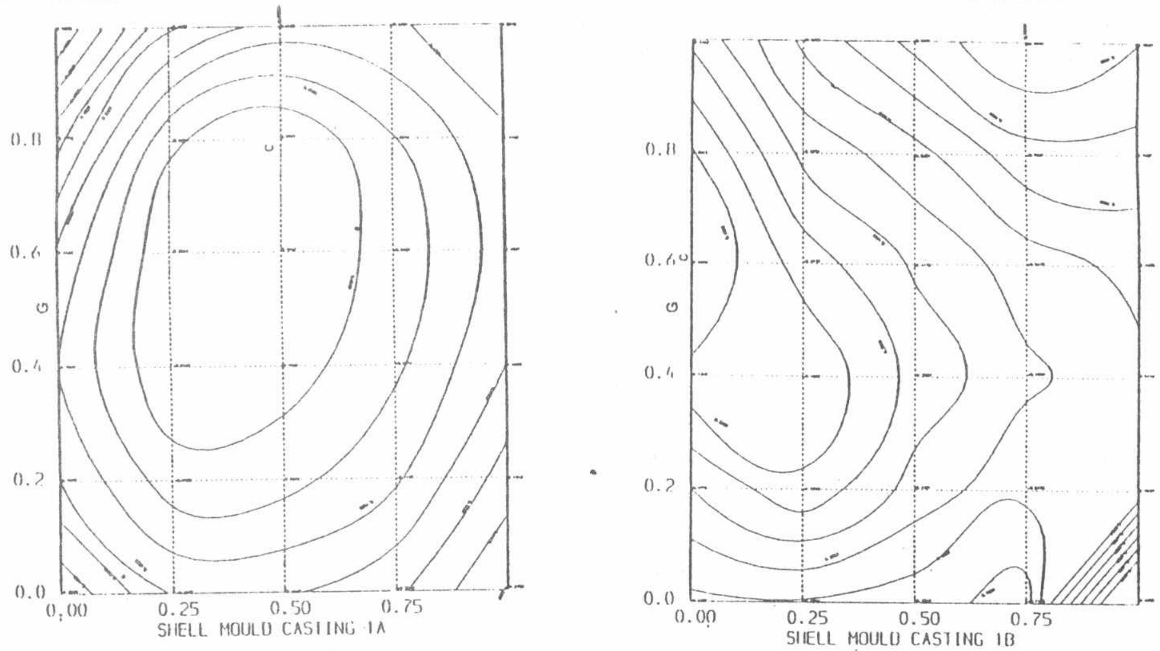
x,y,z are the co-ordinates of the nodal points of sink surface.

$$VA = \frac{V}{A} \tag{12}$$

The ratio between the sink volume and the sink surface VA is strong parameter that qualify the total sink geometry.

QUALITATIVE EVALUATION OF SINKS

Computer aided graphics is a convenient tool for qualitative evaluation of sinks. suitable mean for visulation of the sink is the drawing of its iso-contour lines. This mapping technique may be carried out by sevral techniques. The contour line may be drawn considering linear interpolation between the measured points, or assuming the surface at any point to be paraboloid. The former interpolation method proved to be more efficient in drawing the iso-contour lines and gave precise identification of sink geometry. The points of the contour lines are either joined by straight lines or interpolated smooth curves; example of the two types of iso-contour lines is shown in Fig. (6-a-b) . The later type of line give a



C centre of depression

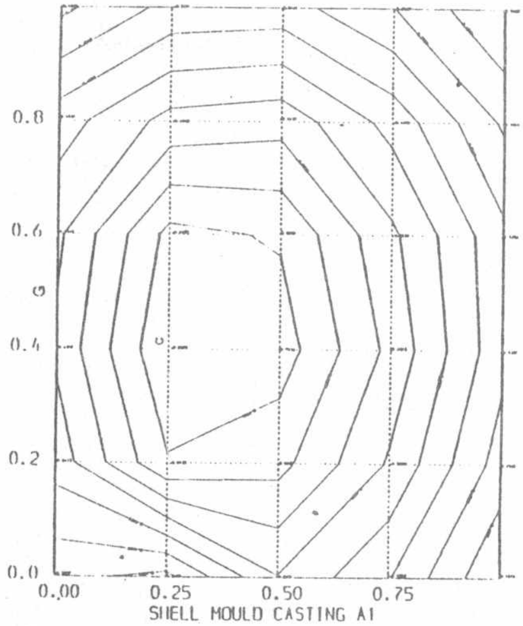
G gate position

Fig. (5) Wax mould iso-contour lines of experiment grop 1.

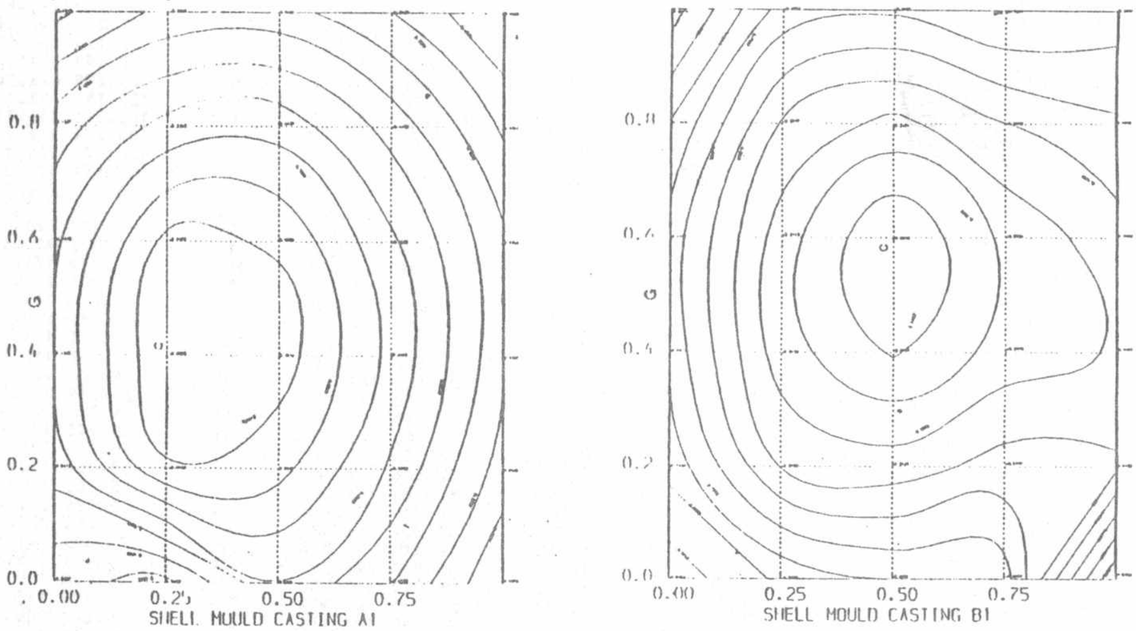
clear picture to the sink form. These types of graphics have been excuted on the ICL 2972 computer system.

EXPERIMENTAL WORK

The exprimental work was covered by about a hundrad of was moulds and the same number of casting components. Originally the objective of the experimental work was to investigates the effect of different dies heat capacities and thermal conductivity on the surface quality of wax mould. Moreover, the effect of gating system insulation (Fig. (3)), and was hydrostatic presssure have showed a pronouned effect in decreasing sink depth. The cast component sink depth is mainly influenced by the superheat temp- peratures of molten metal. But, in the present paper the text is only confind to the qualitative evaluation of the produced cast surfaces. A sample of the measurements carried out in the experimental work is given in table (1), which shows the three dimensional measurements of two wax moulds and



points joined with straight lines



points joined by smooth curve

Fig. (6) Shell mould casting component iso-contour lines of experiment group 1.

two casting components as an example. This samples sums up the last two rounds of expriments which gave the optimum sink geometry.

RESULTS AND DISCUSSION

The quantitative and qualitative evaluation is a helpful tool in sorting out the development in sink geometry. The maximum sink depth and sink volume to surface area ratio have proved to be a satisfactory parameter in qualifying surface geometry. The results of sink evaluation of the last two rounds of experiments, of the sample measurements given in table (1) are shown

Table (1) Sample of measurements of the last two round of experiments

Round 1						Round 2					
Wax mould			Component			Wax mould			Component		
x	y	z	x	y	z	x	y	z	x	y	z
.263	101.059	1.463	.281	101.051	1.043	.251	101.063	.897	.290	91.582	.851
.218	125.791	1.296	.231	125.787	.908	.201	125.797	.291	.262	116.554	.832
.180	150.707	1.206	.196	150.701	.834	.158	150.709	.893	.213	141.832	.825
.144	175.865	1.185	.158	175.851	.809	.116	175.851	.911	.181	166.636	.782
.100	201.335	1.216	.115	201.333	.800	.077	201.339	.960	.144	191.626	.688
.069	225.711	1.338	.022	225.709	.846	.038	225.707	1.040	.098	216.015	.551
25.036	100.686	1.340	26.049	100.682	1.004	26.017	100.689	.840	25.544	91.619	.963
25.992	125.550	.923	26.009	125.549	.885	25.967	125.555	.836	25.502	116.597	.983
25.956	150.870	.816	25.961	150.865	.794	25.934	150.871	.835	25.463	141.561	.938
25.916	175.936	.814	25.932	175.931	.734	25.892	175.945	.843	25.420	167.201	.831
25.879	200.596	.945	25.890	200.597	.707	25.848	200.549	.665	25.385	192.162	.716
25.839	225.742	1.080	25.854	225.739	.774	25.812	225.751	.937	25.345	216.868	.597
50.248	100.731	.966	50.265	100.722	1.064	50.231	100.736	.845	50.398	91.997	1.058
50.210	125.598	.302	50.223	125.592	.952	50.197	125.610	.829	50.363	117.061	1.037
50.170	150.672	.669	50.182	150.666	.849	50.153	150.680	.822	50.321	142.007	.990
50.126	176.048	.682	50.143	176.046	.770	50.124	176.058	.836	50.289	166.453	.900
50.092	201.232	.771	50.102	201.232	.731	50.071	201.240	.854	50.242	191.273	.793
50.055	225.632	.917	50.067	225.628	.781	50.024	225.640	.912	50.199	216.899	.654
75.809	101.121	.931	75.829	101.121	1.155	75.787	101.125	.863	75.846	92.030	1.146
75.770	125.707	.782	75.787	125.707	1.036	75.743	125.723	.841	75.805	117.200	1.113
75.730	150.891	.689	75.747	150.893	.927	75.704	150.903	.819	75.764	142.398	1.063
75.696	175.651	.675	75.710	175.651	.843	75.666	175.665	.339	75.726	166.978	.976
75.655	200.705	.724	75.664	200.709	.806	75.616	200.715	.875	75.692	191.780	.853
75.613	225.563	.635	75.626	225.659	.859	75.574	225.673	.928	75.649	216.508	.725
100.495	101.158	.949	100.512	101.152	1.259	100.478	101.177	.926	100.291	92.434	1.279
100.454	125.478	.819	100.472	125.436	1.161	100.443	125.457	.912	100.256	116.746	1.218
100.415	150.304	.732	100.428	150.504	1.064	100.397	150.319	.888	100.214	142.284	1.147
100.375	175.570	.691	100.392	175.566	.956	100.347	175.573	.902	100.176	166.992	1.061
100.337	200.470	.731	100.352	200.466	.967	100.304	200.481	.944	100.135	192.030	.958
100.295	225.466	.796	100.309	225.462	.988	100.266	225.491	.981	100.097	216.538	.853
.308	91.587	.669	.320	91.585	.917	.294	91.569	.893	.259	101.043	.782
.270	116.553	.802	.276	116.549	.596	.225	116.539	.843	.219	125.779	.716
.226	141.835	.885	.236	141.833	.913	.218	141.819	.832	.180	150.695	.679
.190	166.639	.924	.205	166.631	.960	.186	166.623	.808	.141	175.847	.669
.141	191.621	.882	.167	191.619	.930	.137	191.611	.753	.104	201.329	.639
.108	216.025	.805	.118	216.017	.847	.103	216.009	.687	.060	225.703	.632
25.552	91.627	.737	25.568	91.617	.969	25.550	91.618	.904	26.032	100.671	.821
25.506	116.593	.965	25.522	116.595	1.047	25.501	116.584	.866	25.981	125.541	.749
25.466	141.557	1.074	25.486	141.559	1.040	25.467	141.546	.853	25.952	150.851	.698
25.430	167.205	1.105	25.440	167.199	1.001	25.427	167.190	.817	25.903	175.925	.670
25.386	192.159	1.062	25.406	192.159	.936	25.388	192.154	.775	25.869	200.577	.649
25.355	216.875	.955	25.365	216.367	.837	25.342	216.860	.666	25.836	225.735	.641
50.405	92.001	.756	50.419	91.959	1.008	50.402	91.987	.967	50.248	100.713	.916
50.369	117.069	.963	50.336	117.065	1.055	50.365	117.059	.915	50.205	125.583	.831
50.326	142.011	1.126	50.342	142.009	1.048	50.324	142.003	.886	50.166	150.663	.761
50.271	166.457	1.202	50.299	166.460	.988	50.286	166.443	.840	50.123	176.037	.717
50.249	191.271	1.095	50.265	191.268	.927	50.235	191.261	.771	50.088	201.223	.682
50.211	216.905	.948	50.221	216.898	.830	50.204	216.891	.667	50.052	225.625	.668
75.853	92.037	.748	75.869	92.031	1.000	75.848	92.024	1.042	75.805	101.104	1.051
75.809	117.205	.887	75.831	117.203	1.059	75.813	117.192	.970	75.767	125.598	.950
75.773	142.379	1.021	75.787	142.397	1.045	75.768	142.390	.929	75.730	150.384	.850
75.736	166.979	1.060	75.748	166.979	.982	75.731	166.974	.861	75.695	175.636	.783
75.698	191.781	1.001	75.709	191.781	.893	75.695	191.772	.766	75.647	200.690	.755
75.661	216.507	.875	75.673	216.509	.819	75.656	216.498	.676	75.610	225.656	.724
100.297	92.442	.781	100.311	92.444	.997	100.283	92.431	1.173	100.491	101.149	1.186
100.260	116.750	.872	100.276	116.750	1.024	100.255	116.737	1.096	100.447	125.427	1.105
100.219	142.284	.957	100.234	142.286	1.017	100.222	142.270	1.016	100.411	150.293	1.001
100.184	167.000	.963	100.196	166.998	.971	100.179	166.950	.932	100.374	175.561	.912
100.142	192.032	.930	100.156	192.030	.904	100.137	192.024	.837	100.333	200.459	.856
100.105	216.875	.875	100.117	216.540	.847	100.098	216.526	.770	100.290	225.453	.797

in table (2). From these results it can be seen clearly that surface A usually posses higher maximum sink depth, sink volume and sink volume to surface area ratio than surface B. This was for both wax mould and cast components and was valid for all the experimental work carried out. The computer graphics of the iso-contour lines are shown in Fig. (5,6,7,8). The iso-contour lines are given as a fraction of the maximum sink depth. The graphies showed clearly the identical sink pattern for surface A in Figs. (5-8). These sinks are symmetrical around the point or zone of maximum sink depth. While surface B has different pattern of iso-contour lines but these patterns are almost alike. The reason behind the difference between the general form of iso-contour lines of surface A and B is that the cast left to cool down at the end of working cycle, while surface A upword and B downword. In other words, trapped pool of molten is left to solidfy while the component (plate) in a horizontal position surface A facing upword. The graphics revealed that the iso-contour lines are interrelated to the gating position. Further; the solidification front and solidus isotherms may be deduced from the isocontour lines. The solidification fronts starts at the corners of the wax mould or cast components and moves towards the centre (c) as a solidus isotherms.The

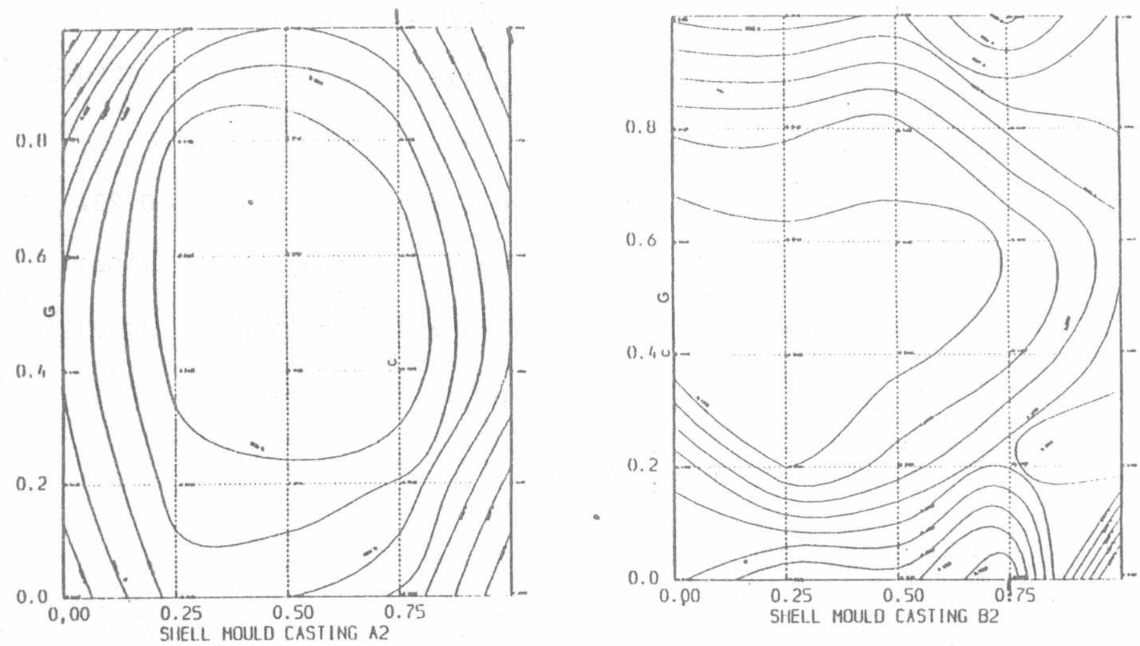


Fig. (7) Wax mould iso-contour lines of experiment group 2.

propagation of solidus isotherms traps a molten of a soft solid skin its shrinkage causes a negative pressure, which create the sink depression.

Table (2) Sample from the results of the last two groups of experiments

		Round 1		Round 2	
Surface	Parameter	Wax mould	Component	Wax mould	Component
A	D	0.252	0.589	0.173	0.330
	V	2372	4439	1661	3134
	A	12504.8	12506.3	12496.1	12507.0
	VA	0.190	0.355	0.133	0.25062
B	D	0.238	0.514	0.082	0.222
	V	1415	2706	333	1104
	A	12472.2	12474.2	12471.0	12471.9
	V	0.113	0.217	0.027	.089

D sink depth in mm

V sink volume in mm^3

A sink surface area in mm^2

VA sink volume to surface area ratio in mm .

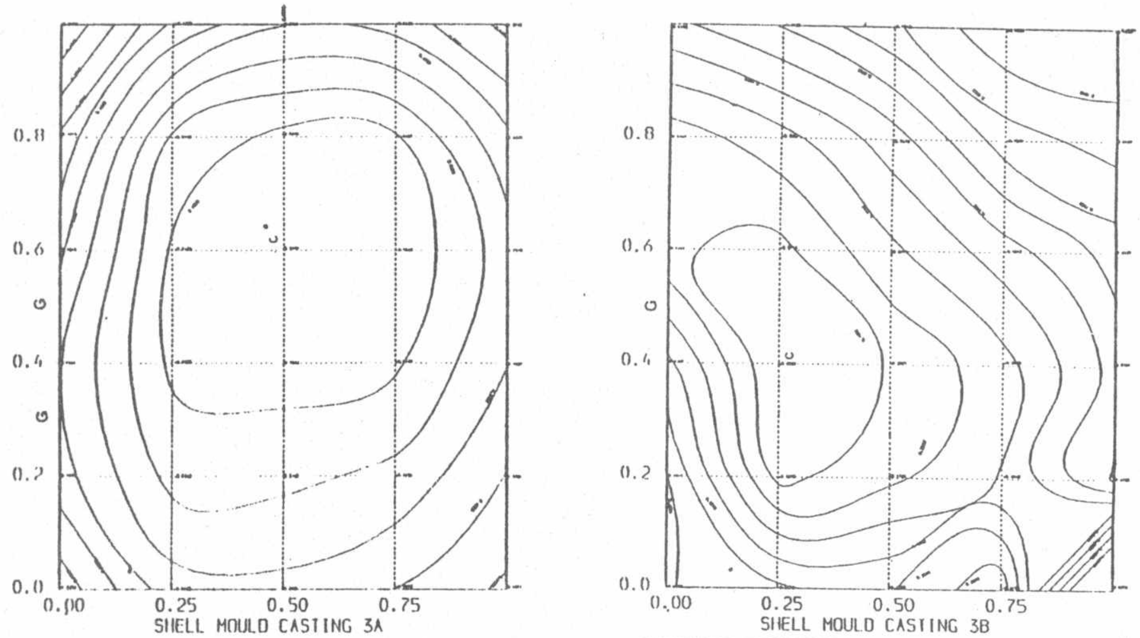


Fig. (8) Shell mould casting component iso-contour lines experiment group 2.

Figures(5-8) shows the centres of depression, which is dependent on the solidus skin (cooling rate) and the temperature of trapped molten.

CONCLUSIONS

1. The use of three co-ordinate measurements in studying surface geometry of cast component is an affective tool.
2. The parameters suggested for quantitative evaluation of the sink geometry; sink volume, sink surface area, maximum sink depth and the ratio of sink volume to surface area are suitable parameters in identifying the surface geometry.
3. The three dimensional measurements and computer graphics can be used for evaluating the performance of more complicated shapes through appropriate mapping technique and surface assessments. This is a significant system in evaluating dies design and performance; where the mathematical procedure of solidification behaviour is not obtainable in predecting the solidification front and solidus isotherms.

REFERENCES

1. J.P. Duncan and G.W. Vickers, Interactive Adjustment of Surfaces, Int. J. Mechanical science, vol. 20, 1978.
2. J.P. Dunean and G.W. Vickers, simplified Method for Interactive Adjustment of surfaces, vol 12 no.6 Nov. 1980 .
3. Shinji Kawabe, Fumihiko Kimura and Tosheo sate, Generation of NC Commands for Sculptured surface Machining from 3-Coordinate Measuring Data, Annals of the CIRP Vol 29/1/1980.

ACNOWLEDGEMENT

The author wish to express his deep appreciation to NEL and NPL (U.K.) Metrology Divisions for their support of this work.