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Characterization of Warpage Phenomenon for an Automotive Blow Moulded Part (820-GMT Filler Panel)

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1. Introduction

One of the major challenges encountered by manufacturers of interior blow moulded parts is to predict the warpage as a function of extrusion blow moulding processing conditions so as to decrease mould modifications prior to manufacturing.

At the end of the blow moulding process, the part is generally cooled down rapidly from above the glass transition or melting point to room temperature. Due to rapid non-uniform cooling, internal stresses will be generated into the finished part. As a result, the final part will deform in order to decrease these internal stresses and cause the warpage phenomenon. This phenomenon is principally governed by the cooling conditions such as the cooling time and moulds temperature.

The aim of this work is to characterize the warpage phenomenon for a planar-shaped carpet part (820-GMT filler panel) manufactured by Lear Corporation, Concord (Ontario). Since this part has a carpet on one of the side, the part cooling is strongly non-uniform and exhibits a non-uniform shrinkage over time that leads to a significant warpage deformation. To eliminate this warpage, Lear Corporation modifies the moulds temperature to get a more uniform temperature distribution during the part cooling.

The objectives of this work are the following:

- To have a better understanding of the processing parameters affecting the warpage of the 820-GMT filler panel. To do so, a series of experiments will be conducted at Lear Corporation;
- To help validating the new warpage feature that will be implemented into BlowSim software.

This work, called task #3, has been planned into the joint international project IMI-IMTI-Taiwan/Lear.

2. Experiments Description

First, I would like to recall the important steps during the blow moulding process of the 820-GMT filler panel:

- On the cavity mould side, the cooling channels are fed with the city water with a temperature around 50°F.
- On the core mould side, the mould channels are fed with a hot oil sets approximately at 140°F.
- A polypropylene (PP) carpet is put inside the cavity mould with a robot;
- A small amount of water is vaporized on the carpet side that will become in contact with the parison. When the hot parison molten polymer contacts the carpet, this water will be vaporized and the parison temperature will go down more rapidly since the water latent heat of vaporization is very high (2260 kJ/kg). At the same time, that will avoid the parison polymer to penetrate into the carpet and eliminate the possibility of viewing some black spots on the other side.
- The parison is extruded during 3.5 s at temperature of 204°C.
- The parison is pinched at the bottom and at the same time, a pre-blow pressure is applied;
- The moulds are closing and the parison is inflated;

- The total cycle time is 86 sec (then cooling time is approximately 80 sec);
- The part is taken out from the moulds, the flash is removed with a cutter and we end up with four pieces.
- These pieces are put carpet down and fed into a cooling rack having three cooling fans. The residence time in this cooling rack is approximately 1 minute;
- After that, those pieces are assembled into two different panels connected with a spring-loaded hinge.

To have a better understanding of the warpage phenomenon, we decided to play with 4 different processing parameters:
- Cooling time (t_c);
- Cavity mould temperature (T_{m1});
- Core mould temperature (T_{m2});
- Presence of carpet (making parts with and without carpet);

It would have been interested to study the influence of water vaporization on the warpage. Since these experiments have been conducted on the production line without any interruption, we decided to make only one experiment studying the influence of this parameter on the warpage results.

When the filler panel warps, it yields to a banana-shaped part (Fig. 1). One way to quantify this warpage is to measure the maximum part deflection and its position when a line passes through its extremities (Fig. 2). The evaluation of deflection has been made on the part with the flash since it will be easier to compare with the warpage calculation that will be performed with BlowSim in a subsequent study. Also, parts have not been placed into the cooling rack to cool them down. Instead, we let them cool down at ambient temperature to evaluate the warpage without any forced cooling. We observed that warpage is strongly influence by how the part is positioned when it is cool down. Since the part is still hot when removing it from the moulds, the gravity will interfere with the warpage phenomenon. We found that the best way to position the part for cooling it down is to put it on one of its edges.

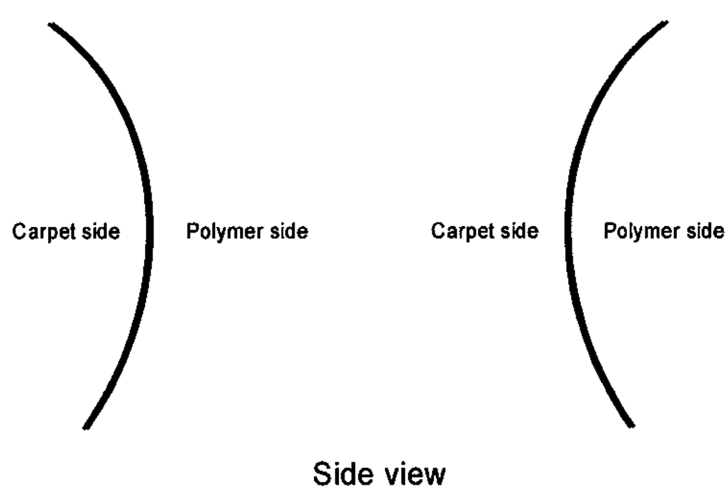


Figure 1. Illustration of banana-shaped part after cooling.

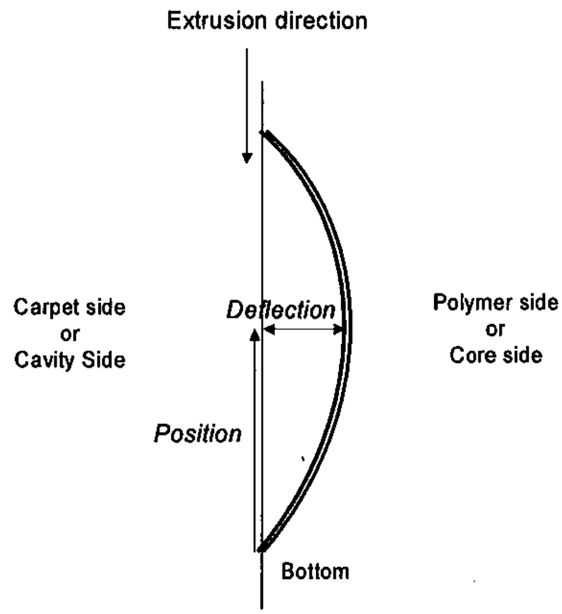


Figure 2. Illustration of the warpage evaluation.

Tables I to IV and Figures 1 and 2 summarize the warpage results obtained for different mould temperature set-ups. You could also find in Annexe A all photos illustrating parts after each experiment. Several observations can be drawn from these results:

- Since the carpet reacts as an insulating material, the heat transfer is lower on this side and the time to cool this side down is higher. To compensate this effect, Lear has proposed to decrease the cavity mould temperature to improve the heat removal and decrease the cycle time as much as possible. Even with this low cavity mould temperature, the cavity part side will be hotter than the core part side if the core mould is let at ambient temperature for example. Instead, Lear proposed to increase the core mould temperature to end up with a part having a more uniform temperature distribution and the final cooling is completed into the cooling rack. However, for our experiments, we used a different configuration since the part has been cool down at ambient temperature after removing it from the moulds in order to let the thermal stress releases so the part will shrink and finally warp;

- When the part is blow moulded with a carpet, one can notice that:

    - If the cooling time increases (t_c), the part deflection decreases caused by a more uniform temperature distribution when the part is cooling down;

    - if the core mould temperature decreases (T_{m2}) (and the cavity mould temperature (T_{m1}) is set to 10°C), the part deflection increases excepted when the core mould temperature (T_{m2}) equals to 51.7°C;

    - when the mould temperature is set-up at T_{m1}=10°C and T_{m2}=60°C, the water vaporization on the carpet tends to decrease the warpage level since the cavity part side cools down more rapidly. This is the actual operating conditions used by Lear. It still exists some small warpage (15 mm) but once

Table I. Mould Temperature Set-up # 1

- Water temperature fed into channel cavity mould (cold mould) : ≈ 10°C
- Temperature monitored at the surface of the cavity mould during experiments (T_{m1}): 15.5°C (top), 14.4°C (centre), 13.6°C (bottom).

- Heating fluid temperature fed into channel core mould (hot mould) : 60°C
- Temperature monitored at the surface of the core mould during experiments (T_{m2}): 56.5°C (top), 56.4°C (middle), 56.3°C (bottom).

Experiment number	With (W)/ Without (WO) Carpet	Cooling Time (s)	Warpage Evaluation		
			Deflection measured on Cavity/Core side	Deflection (mm)	Position (mm)
1	W*	86	Cavity	15	900
2	W**	86	Cavity	35	550
3	WO	86	Core	30	500
4	W	46	Cavity	40	1050
5	WO	46	Core	16	900
6	W	120	Cavity	10	1130
7	WO	120	-	0	-

* This is the actual operating conditions used by Lear to manufacture this part.
** No water vaporization on the carpet.

Table II. Mould Temperature Set-up # 2

- Water temperature fed into channel cavity mould (cold mould) : ≈ 10°C
- Temperature monitored at the surface of the cavity mould during experiments (T_{m1}): 15.0°C (top), 15.0°C (centre), 14.0°C (bottom).

- Heating fluid temperature fed into channel core mould (hot mould) : 51.7°C
- Temperature monitored at the surface of the core mould during experiments (T_{m2}): 48.5°C (top), 48.5°C (middle), 48.5°C (bottom).

Experiment number	With (W)/ Without (WO) Carpet	Cooling Time (s)	Warpage Evaluation		
			Deflection measured on Cavity/Core side	Deflection (mm)	Position (mm)
8	W	86	Cavity	10	650
9	WO	86	-	0	-
10	W	46	Cavity	35	1000
11	WO	46	-	0	-
12	W	120	Core	10	850
13	WO	120	Core	20	670

Table III. Mould Temperature Set-up # 3

- Water temperature fed into channel cavity mould (cold mould) : ≈ 10°C
- Temperature monitored at the surface of the cavity mould during experiments (T_{m1}): 15.4°C (top), 13.5°C (middle), 13.5°C (bottom).

- Heating fluid temperature fed into channel core mould (hot mould) : 40.6°C
- Temperature monitored at the surface of the core mould during experiments (T_{m2}): 37.4°C (top), 38.4°C (centre), 37.4°C (bottom).

Experiment number	With (W)/ Without (WO) Carpet	Cooling Time (s)	Warpage Evaluation		
			Deflection measured on Cavity/Core side	Deflection (mm)	Position (mm)
14	W	120	Cavity	15	970
15	WO	120	-	0	-
16	W	86	Cavity	50	650
17	WO	86	Core	18	750
18	W	46	Cavity	75	550
19	WO	46	Core	16	550

Table IV. Mould Temperature Set-up # 4

- Water temperature fed into channel cavity mould (cold mould) : shut off
- Temperature monitored at the surface of the cavity mould during experiments (T_{m1}): 39°C (top), 37°C (centre), 37°C (bottom).

- Heating fluid temperature fed into channel core mould (hot mould) : 60°C
- Temperature monitored at the surface of the core mould during experiments (T_{m2}): 64°C (top), 64°C (middle), 62°C (bottom).

Experiment number	With (W)/ Without (WO) Carpet	Cooling Time (s)	Warpage Evaluation		
			Deflection measured on Cavity/Core side	Deflection (mm)	Position (mm)
20	W	86	Cavity	57	570
21	WO	86	Core	3	1200
22	W	120	Cavity	25	570
23	WO	120	Core	10	950
24	W	160	Cavity	10	1100
25	WO	160	Core	30	1300

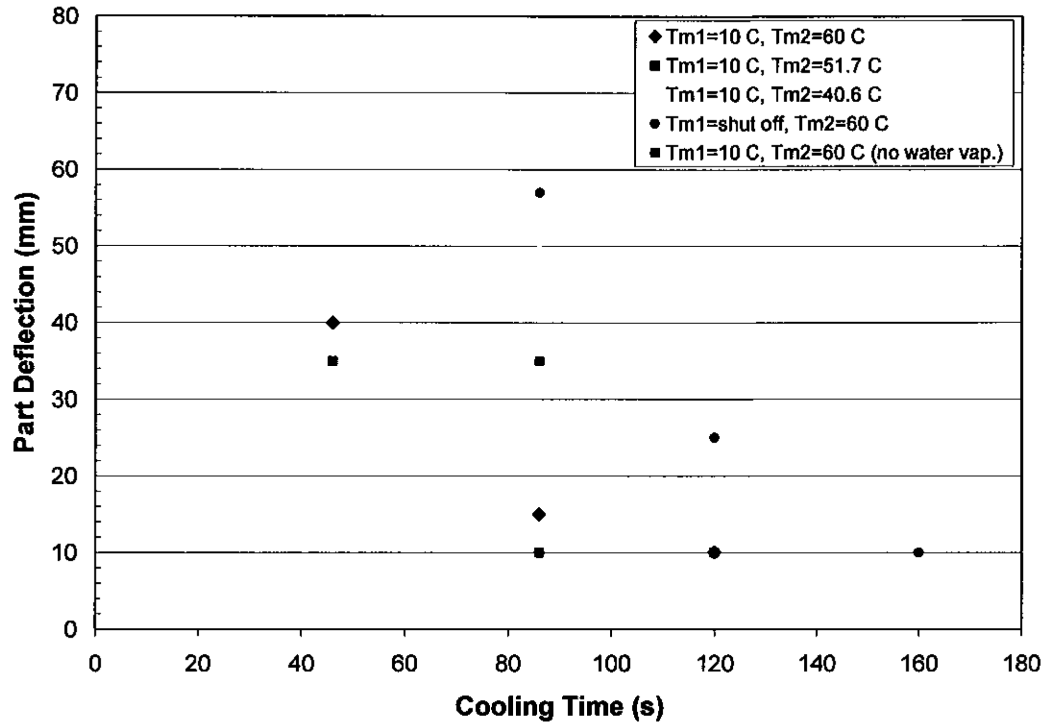


Figure 1. Part deflection (with carpet) vs cooling time for different moulds temperature set-ups.

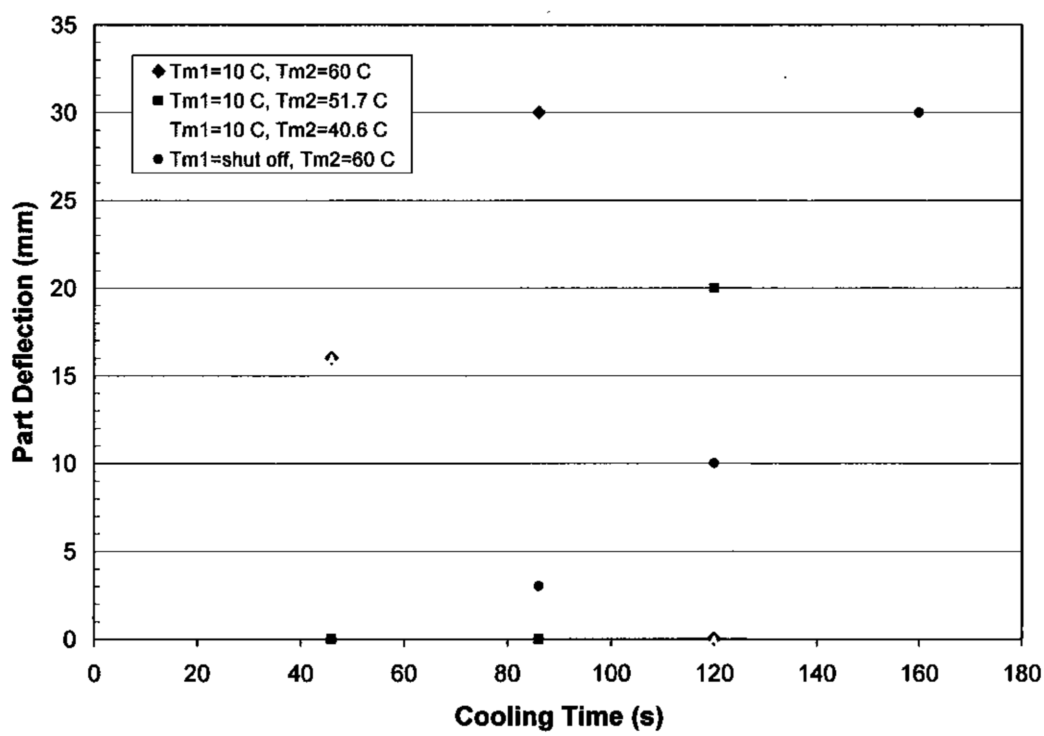


Figure 2. Part deflection (without carpet) vs cooling time for different moulds temperature set-ups.

the part is cut and cool down into the cooling rack, this warpage disappears;

- for all cases excepted when t_{m1}=10°C and T_{m2}=51.7°C, deflection occurs on the cavity side meaning that this side becomes warmer than the other side when the part is taken out from the moulds;

- when mould temperature is set-up to T_{m1}=10°C and T_{m2}=51.7°C, the part deflection is lower or has the same degree of magnitude to the Lear's actual operating conditions (T_{m1}=10°C and T_{m2}=60°C). Then by using this new mould temperature set-up, Lear could benefit from this situation by decreasing his energy consumption cost;

- when cold water is shut off for the cavity mould temperature, the cavity mould temperature surface increases and leads to a highest degree of warpage compared to the other mould temperature set-ups.

- When the part is blow moulded without carpet, one can notice that:

  - for all mould temperature set-ups, when the part is taken out from the moulds, the cavity part side is always colder than the core part side. Then, the deflection will always occur on the core side (the hotter side). Unexpectively, some experiments #7, #9, #11 and #15 exhibit no warpage even if there is a temperature difference between the two moulds. At this stage, we presume that these results happened since, for these experiments, parts have been cooled down by putting them carpet down on the table;

  - in general, when the cooling time increases, the part deflection increases since the part temperature deviation between the cavity and the core sides when the part is taken out from the moulds increases as well. This is not true for two experiments #7 and #15 likely due to the same assumption as the previous one;

The next step is to evaluate the mould heat transfer coefficient, by using numerical simulations, on the carpet side since this material acts as an insulating material. As expected, the water vaporization will influence this heat transfer and will tend to increase it. To evaluate this heat transfer coefficient, we will use the actual operating conditions utilized by Lear (experiment #1: t_c=86 s, T_{m1}=10°C, T_{m2}=60°C) and try to find the right heat transfer coefficient to get the same part deflection. After that, we will use this heat transfer coefficient to predict the warpage (part deflection) for the other operating conditions.

To evaluate the warpage capability of BlowSim, I propose to predict the warpage for the next operating conditions:

- Parts without carpet (these experiments can be done right now since both sides have the same heat transfer coefficient)
  - Experiments #3, #5, #9, #17 and #21

- Parts with carpet:
  - Experiments #1 (already done when estimating the mould heat transfer coefficient), #4, #6, #8, #16, #18 and #20

During this validation, we will start to develop an optimization strategy to minimize the warpage level that is what is the right mould temperature set-up and cooling time in order to minimize the part deflection. After that, if the warpage is minimized but not zero, we are going to develop a strategy to modify the mould geometry prior to manufacturing.

Annexe A Photos illustrating parts after each experiment

Experiment #1

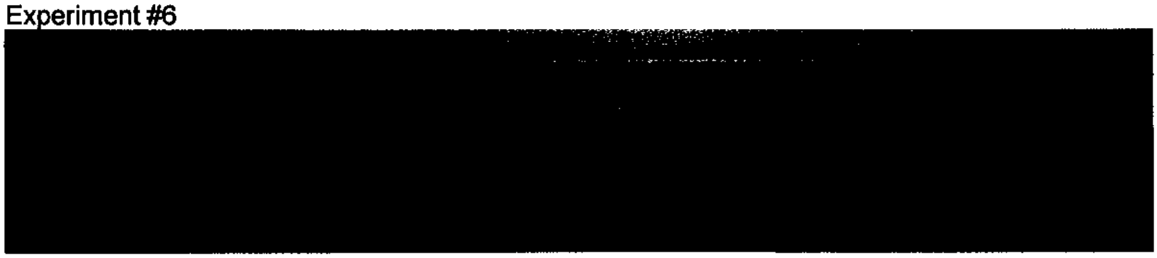
Experiment #2

Experiment #3

Experiment #4

Experiment #5

Experiment #6



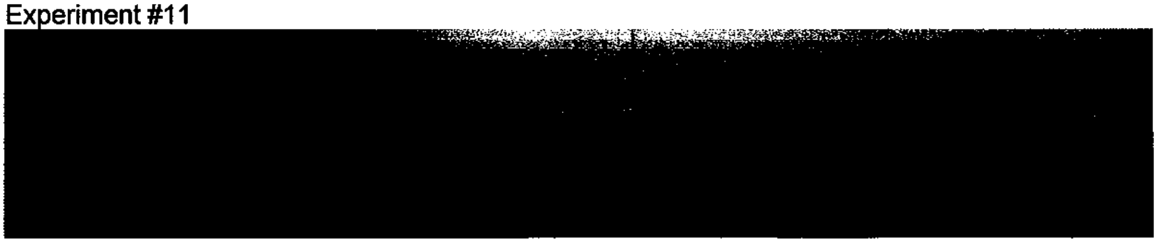
Experiment #7

Experiment #8

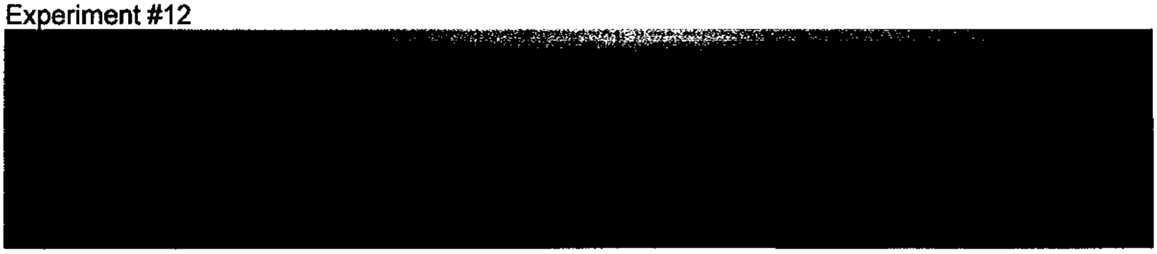
Experiment #9

Experiment #10

Experiment #11



Experiment #12

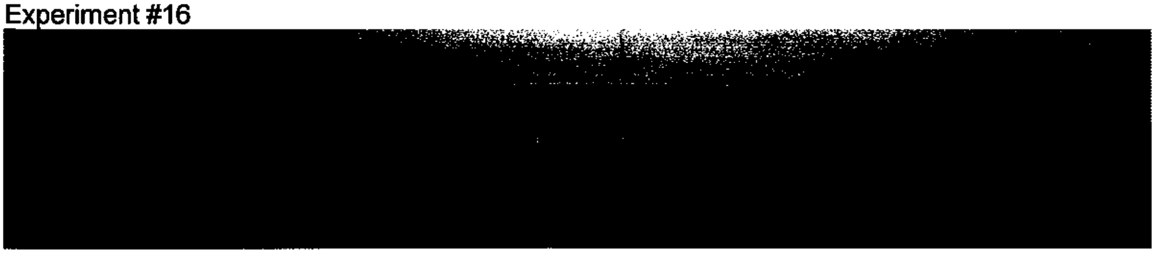


Experiment #13

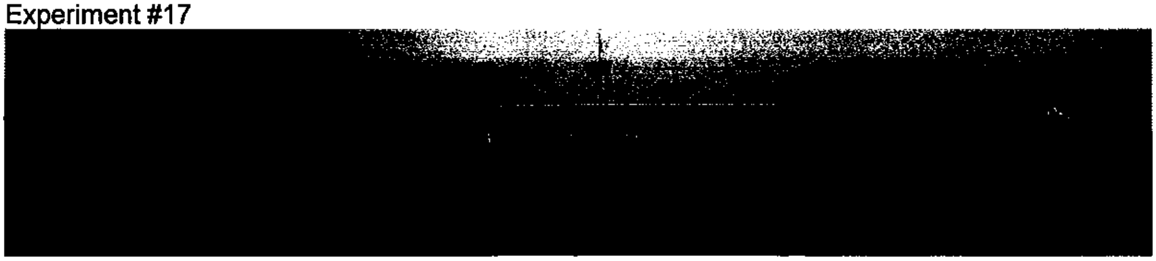
Experiment #14

Experiment #15

Experiment #16



Experiment #17

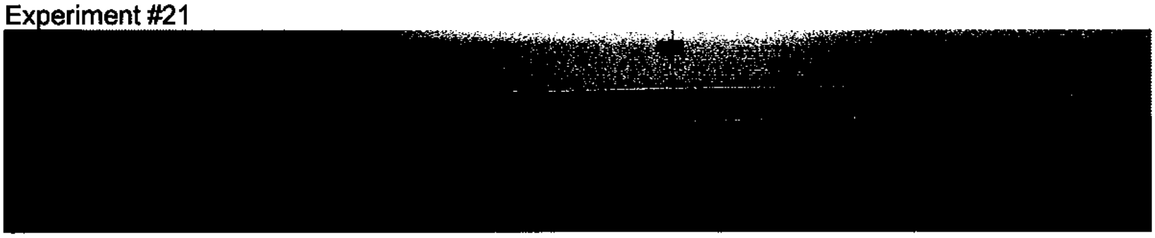


Experiment #18

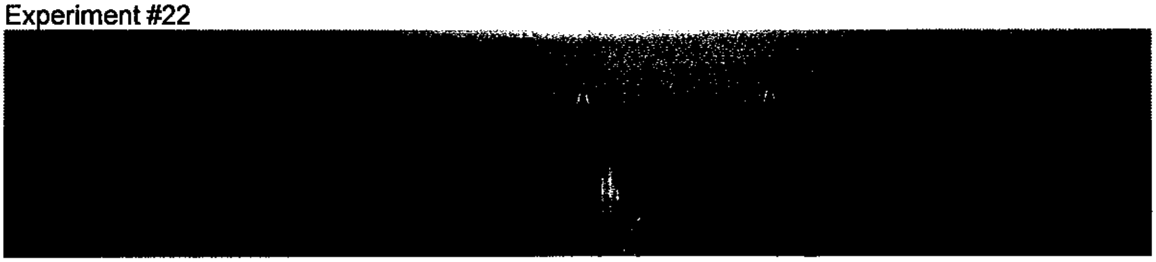
Experiment #19

Experiment #20

Experiment #21



Experiment #22



Experiment #23

Experiment #24

Experiment #25

[redacted]