POROSITY IN AMALGAM RESTORATIONS
AS INFLUENCED BY MIX PLASTICITY

Douglas G. Campbell, D.M.D.

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APPROVAL

[redacted]

A. E. Retzlaff, D.D.S.
Director
Graduate Pedodontic Program

[redacted]

D. B. Mahler, Ph.D.
Chairman
Department of Dental Materials Science

ABSTRACT

Under clinically simulated conditions, amalgams made from five different alloys at three plasticities (slightly dry, ideal and slightly wet) were studied for marginal porosity and residual mercury. Significant differences in porosity were found between dry and ideal or wet plasticities. While differences in residual mercury were found between dry and ideal plasticities, they were too small ($<1\%$) to have any clinical significance. It was concluded that amalgams mixed at an ideal or slightly wet plasticity can result in margins with significantly less porosity, but not more residual mercury than amalgams mixed at a dry plasticity.

ACKNOWLEDGEMENTS

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INTRODUCTION

It has been demonstrated that porosity can significantly affect the physical properties of dental amalgam. Jorgensen[1] estimated that a one percent increase in porosity can reduce the crushing strength of amalgam by as much as 500 kg/cm^2, or about 13%. In a later paper, Jorgensen[2] showed that an amalgam prepared with an increased mix plasticity (high pre-condensation mercury content) had significantly better marginal adaptation than an amalgam prepared with a decreased mix plasticity (lower pre-condensation mercury). Additionally, the amalgam prepared with the higher mix plasticity exhibited less internal porosity.

Besides its influence on strength, Jorgensen[3] further hypothesized that porosity can increase the rate and amount of corrosion in three ways: (1) by providing a pathway for electrolytes into the amalgam; (2) by increasing the surface area of the tin-mercury phase (γ_2); and (3) by allowing for lower oxygen tension in the depths of the porosity. The significance of this potential porosity-corrosion relationship is that marginal fracture, one of the principal modes of amalgam failure, is considered to be caused by corrosion and therefore could be influenced by porosity.

In the 1966 and 1967 studies, Jorgensen[1,2] used extremes in mercury content to prove that increasing the pre-condensation mercury reduced the porosity in the set amalgam. For mechanical condensation, 45% to 65% mercury were used and for hand condensation, 48% (traditional and Eames techniques) and 58% (wet technique) were used. In clinical practice, these very wet mixes would necessitate the use of multiple mixes, could result in high residual mercury content, are certainly more difficult to manage, and generally result in a longer time before carving can begin. In addition, these two extremes in mercury content (very dry and very wet) do not represent the range used in normal clinical practice. Furthermore, Jorgensen used cylindrical metal molds that were not similar to cavity preparations in teeth, and the amalgam was condensed with forces greater than normally used in clinical practice[1,2,4]. Because of these atypical experimental conditions, the question was raised whether the same conclusions would prevail with experimental conditions more closely approximating clinical practice.

Therefore, the purpose of this study was to investigate the porosity in the margins of amalgam restorations under conditions more closely simulating clinical practice, and to determine the effect on the porosity of changes in plasticitiy resulting from small changes in pre-condensation mercury.

MATERIALS AND METHODS

As Jorgensen has shown, the significant factor affecting porosity is the pre-condensation mix plasticity which in effect is determined by the mercury used in the amalgam mix. Other factors affecting mix plasticity would be the alloy particle nature, size and distribution. In this regard, five alloys were selected which were considered to be representative of the differences in particle nature, size and distribution of commercially available alloys. A description of these alloys is given in Table I.

TABLE I

)Y	PARTICLE COMPOSITION	PARTICLE NATURE	PARTICLE SIZE
True ;alloy ;ch #139740)	Traditional	Chip	Fine
staloy ;ch #05117811)	Traditional	Chip	Micro
eraloy ;ch #0420772077)	Traditional	Spherical	
ln ;ch #0627602)	High Copper	Spherical	
persalloy ;ch #4F125)	Traditional (66.6%) Silver-Copper (33.3%) Eutectic	Chip) Spherical) Blend	

All alloys were tested at three different plasticities: (1) ideal; (2) wet (+2% mercury); (3) dry (-2% mercury). Ideal plasticity was subjectively determined by 'balling' the mix in the palm of the hand and by tactile inspection of the plasticity by smearing the mix. It was felt that these mercury levels (±2%) would approximate the range used in normal clinical practice.

In Table II the mercury percentages and methods of preparation of each of the alloys is presented.

TABLE II

	% MERCURY			AMALGAMATION		CAPSULE &
	DRY	IDEAL	WET	TIME (sec)	AMALGAMATOR	PESTULE
?rue lloy	49	51	53	15	Wig-L-Bug	S.S.W.
aloy	53	55	57	6	Varimix	S.S.W.
aloy	46	48	50	8	Varimix	S.S.W.
[illegible]	41	43	45	9	Varimix	S.S.W.
rsalloy	51	53	55	13	Varimix	Caulk

The amalgams were condensed into a plastic tooth model having a typical Class II cavity preparation (Fig. 1). The lingual wall was prepared flat to facilitate the porosity determination. All restorations were hand condensed with a condenser having end diameters of 2.0 mm. and 1.2 mm. Condensation forces used were in the range of 2.5 to 3.0 pounds (1.14 to 1.36 Kg.) and monitored on a dynamic force measuring device. The resultant pressures were 1.0 to 1.2 Kg/mm^2 for the 1.2 mm. condenser face, and 0.36 to 0.43 Kg/mm^2 for the 2.0 mm. condenser face. This condensation force range has been shown by Basker and Wilson[4] to be typical of forces used in clinical practice. The small condenser face was used in those areas of the cavity preparation which would not permit use of the large condenser face because of size restrictions.

Excess mercury was removed during condensation when this excess exceeded approximately 0.25 mm. The total time to the end of condensation was no greater than four minutes. The occlusal-buccal margin was removed immediately after carving for final mercury content determination.

After setting, the plastic teeth were split, and the samples embedded, occlusal-lingual wall down, in clear plastic. Polishing was done initially by hand, and then with rotating polishing wheels and diamond abrasives of increasing fineness from 15μ to 1μ.

The samples were etched with nitric acid[3] to clear porosities of debris and to accentuate spherical particles so that intra-particle porosities could be visualized and excluded from final porosity counts. The amount of etching required to produce the desired results was determined subjectively by microscopic inspection of the etched sample. Table III gives the concentration of nitric acid and time used for each alloy.

TABLE III

ALLOY	NITRIC ACID	TIME
NTD	30%	10-20 Sec.
Aristaloy	30%	10-20 Sec.
Spheraloy	10%	8-9 Min.
Tytin	30%	20-30 Sec.
Dispersalloy	10%	3-4 Min.

Ten uniformly spaced photographs were taken of the margins of each specimen along the flat occlusal-lingual wall. The total field on these photographs represented two-thirds of the total length of the occlusal-lingual margin. The prints used to determine porosity had magnification of 180X. Figures II-VI show representative photos of each of the alloys.

Marginal porosity was determined by a point counting method similar to that described by Jorgensen[2]. Lines 28 mm. apart (corrected for magnification this representes 0.16 mm. on the sample) were drawn on each photograph such that they included the occlusal most portion of the margin without including surface irregularities. The photograph was placed on the view box (Fig. VII) with a clear plastic point grid placed over it such that approximately 203 points were included between the two lines. These points were approximately 0.2 mm. in diameter and were equally spaced 3.9 mm. apart. Porosities were counted that were larger in size than the point and that coincided with the point or the greatest portion of the point. The volume percent porosity of a given sample was calculated by the formula below:

$$\text{Volume \% Porosity} = \frac{\text{\#Porosity-Point Coincidences}}{\text{Total \#Points}} \times 100$$

An example is given below:

Total porosity-point coincidences in 10 photographs (one sample) = 94

Total points in 10 photographs = 2030

$$\text{Volume \% Porosity} = \frac{94}{2030} \times 100 = 4.63\%$$

RESULTS AND DISCUSSION

1. Porosity

The data was treated by a two-way analysis of variance (ANOVA), using five alloys and three plasticities as the variables. Differences in means were determined using Tukey's Contrast. Table 1. presents the mean porosities for the alloys at the different plasticities; in Figure VIII porosity is plotted versus plasticity for the five alloys; and Table 2. presents the results of the two-way ANOVA.

Table 2. shows that the effect of both plasticity and alloy is significant at $p<0.01$, with significant interaction. Using Tukey's Contrast it was found that differences in alloy means greater than 1.529% were significant at $p<0.05$. New True Dentalloy has significantly more marginal porosity than any of the other alloys studied; Spheraloy has the lowest porosity, but not significantly less than Dispersalloy.

Using Tukey's Contrast it was found that differences in plasticity means greater than 1.009% were significant at $p<0.05$. Both ideal and wet plasticities have significantly less porosity than the dry plasticity with no difference between ideal and wet plasticities. These results would indicate that while there is decreased marginal porosity with increased plasticity, it may not be necessary to use an overly wet mix.

Using Tukey's Contrast it was found that differences in porosity means within alloys greater than 2.256% were significant at $p<0.01$. Table 3. presents mean porosity for each of the alloys at each of the plasticities used, with bars connecting means with no significant difference.

Although Dispersalloy and Spheraloy failed to show a significant difference in porosity between dry and wet plasticities, they did fit the pattern of decreased porosity with increased plasticity shown by the three other alloys studied. This pattern would indicate that there is an advantage of less marginal porosity with an ideal or slightly wet mix.

2. Marginal Residual Mercury

The data was treated by a two-way analysis of variance using five alloys and three plasticities as the variables. Differences in means were determined using Tukey's Contrast. Table 4. presents the mean marginal residual mercury for the alloys at the plasticities studied; in Figure IX marginal residual mercury is plotted versus plasticity for each of the five alloys; and Table 5. presents the results of the two-way ANOVA.

The presults in Table 5. show that both alloy ($p<0.01$) and plasticity ($0.01<p<0.05$) have a significant effect on residual mercury in the set amalgam margin.

Using Tukey's Contrast it was found that differences in mean residual mercury between the three plasticities greater than 0.749% were significant at $p<0.05$. We thus see that while the ideal plasticity results in more residual mercury than the dry plasticity, the wet plasticity does not significantly increase the residual mercury as compared to either the dry or ideal. However, the differences in marginal residual mercury (<1.0%) are so small that it is doubtful that they would have anyclinical significance.

These results would indicate that with average condensation forces and removal of excess mercury during condensation, one could use a slightly wet mix without weakening the margins with increased residual mercury.

Tukey's Contrast was used to determine differences in means within alloys. Differences in means greater than 1.674% was found to be significant at $p<0.05$. Table 6. presents the marginal residual mercury for each of the alloys at each of the plasticities studied. Only Tytin demonstrated a significant increase in marginal residual mercury between dry and ideal or wet plasticities. In all remaining alloys there was no difference in marginal residual mercury between any of the three plasticities. These results further substantiate the conclusion drawn from Table 5.

The results of this study, that a wet mix compared to a dry mix results in significantly less porosity, but not significantly more residual mercury in the set amalgam margin, would indicate that slightly wet amalgam mixes can result in superior amalgam margins. Furthermore, to obtain a significant decrease in porosity, one need not use a very wet mix. Thus, potential problems associated with wet mixes can be avoided; i.e., the need for multiple mixes, long setting times, and difficulties in management of the mix during condensation. With adequate condensation forces and removal of excess mercury during condensation, previous concerns for increased residual mercury in the margins with increased plasticity of the mix has not been born out.

SUMMARY AND CONCLUSIONS

In this investigation an evaluation was made of the porosity and final mercury content of the margins of amalgam restorations placed under simulated clinical conditions. For the five alloys studied, the following conclusions were drawn:

1. An ideal or slightly wet plasticity of the pre-condensation mix when compared to a dry mix, resulted in significantly less porosity in the amalgam margin.

2. Small changes in pre-condensation mix plasticitiy did not significantly change the final mercury content at the amalgam margin.

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3. Jorgensen, K.D., Structure and Corrosion of Dental Amalgam. Acta Odont. Scandinav., 28:129-142, 1970.

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Table 1.

Effect of Pre-Condensation Mix Plasticity and Alloy on the Volume Percent of Intermal Porosity in Amalgam Restoration Margins

	Plasticity			
Alloy	Dry (-2% Hg)	Ideal	Wet (+2% Hg)	Mean*
New True Dentalloy	10.16	6.74	7.35	8.08
Aristaloy	9.74	4.60	3.18	5,84
Tytin	7.85	5.30	5.25	6.13
Dispersalloy	5.50	5.33	3.97	4.93
Spheraloy	5.43	4.22	3.26	4.31
Mean*	7.74	5.24	4.60	

* Bars join means with no significant difference.

Table 2.

Marginal Amalgam Porosity as Effected By

Pre-Condensation Mix Plasticity and Alloy

Two Factor Analysis of Variance

Source	SS	df	MS	F	p
Alloys	99.46395	4	24.86599	14.46022	p<0.01
Plasticities	109.78879	2	54.89440	31.94195	p<0.01
Interaction	45.00306	8	5.62538	3.27330	p<0.01
Error	77.33553	45	1.718567	1.00000	

Table 3.

Effect of Alloy and Plasticity on the Volume Percent of Internal Porosity in Amalgam Restoration Margins

Alloy	Plasticity	Porosity (Volume %)*
New True Dentalloy	Dry (-2% Hg)	10.16
	Ideal	6.74
	Wet	7.35
Aristaloy	Dry	9.74
	Ideal	4.60
	Wet	3.18
Tytin	Dry	7.85
	Ideal	5.30
	Wet	5.25
Dispersalloy	Dry	5.50
	Ideal	5.33
	Wet	3.97
Spheraloy	Dry	5.43
	Ideal	4.22
	Wet	3.26

* Bars connect means with no significant difference.

Table 4.

Effect of Pre-Condensation Mix Plasticity and Alloy on the Residual Mercury in Amalgam Restoration Margins

	Plasticity				
Alloy	Dry (-2% Hg)	Ideal	Wet (+2% Hg)	Mean	Ideal Pre-Condensation Mercury
New True Dentalloy	48.80	48.77	48.51	48.69	51
Aristaloy	53.72	54.11	54.09	53.97	55
Tytin	40.81	42.44	43.43	42.23	43
Dispersalloy	50.37	50.78	50.18	50.45	53
Spheraloy	52.60	53.96	53.65	53.41	48
Mean*	49.26	50.01	49.97		

* Bars join means of no significant difference.

Table 5.

Marginal Residual Mercury as Effected by Pre-Condensation Mix Plasticity and Alloy

Two Factor Analysis of Variance

Source	SS	df	MS	F	p
Alloys	1072.70419	4	268.17604	283.45028	$p<0.01$
Plasticity	7.17374	2	3.58687	3.79116	$0.01<p<0.05$
Interaction	12.32398	8	1.54050	1.62824	NS
Error	42.57509	45	0.94611	1.00000	

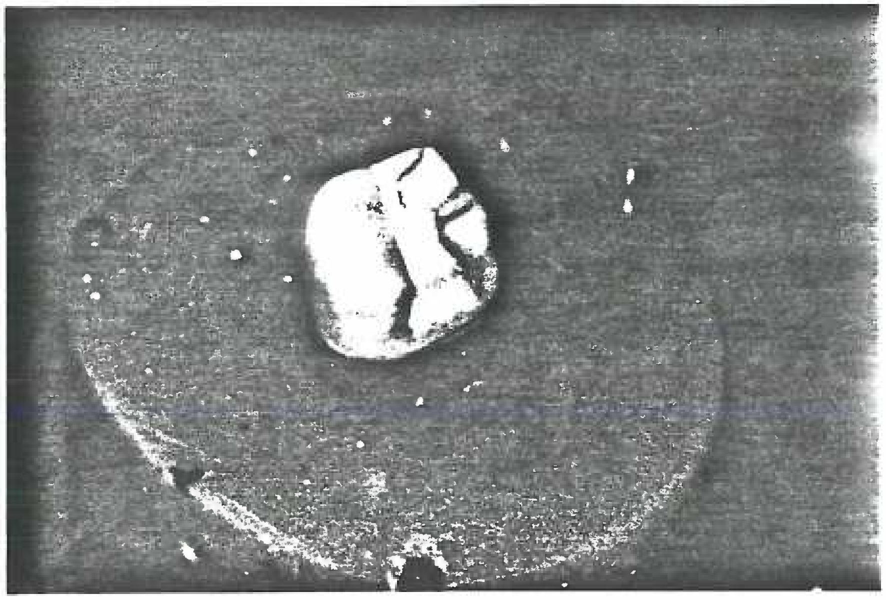
Table 6.

Effect of Pre-Condensation Mix Plasticity and Alloy on the Residual Mercury in Amalgam Restoration Margins

Alloy	Plasticity	Marginal Residual* Mercury
New True Dentalloy	Dry (-2% Hg)	48.80
	Ideal	48.77
	Wet (+2% Hg)	48.51
Aristaloy	Dry	53.72
	Ideal	54.11
	Wet	54.09
Tytin	Dry	40.81
	Ideal	42.44
	Wet	43.43
Dispersalloy	Dry	50.37
	Ideal	50.78
	Wet	40.18
Spheraloy	Dry	52.60
	Ideal	53.96
	Wet	53.65

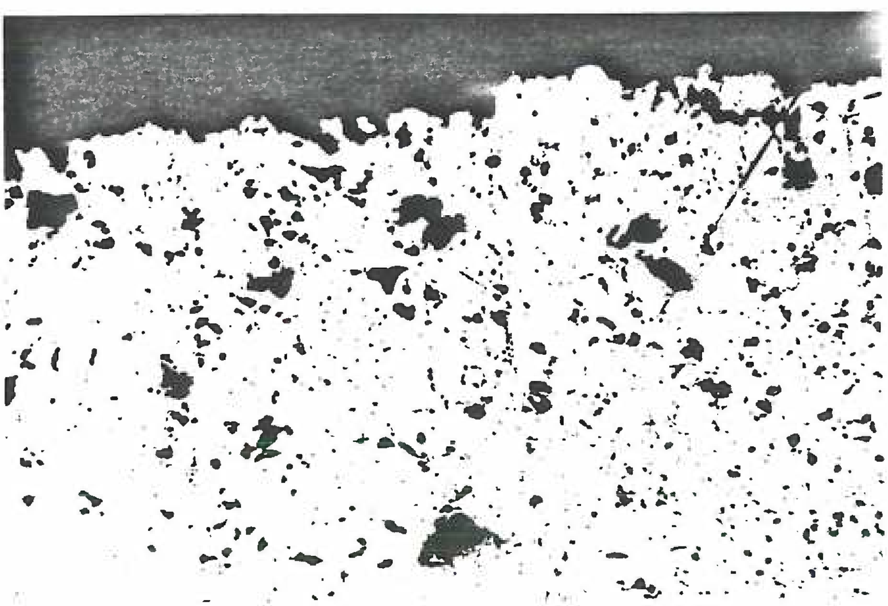
* Bars connect means with no significant difference.

Figure I



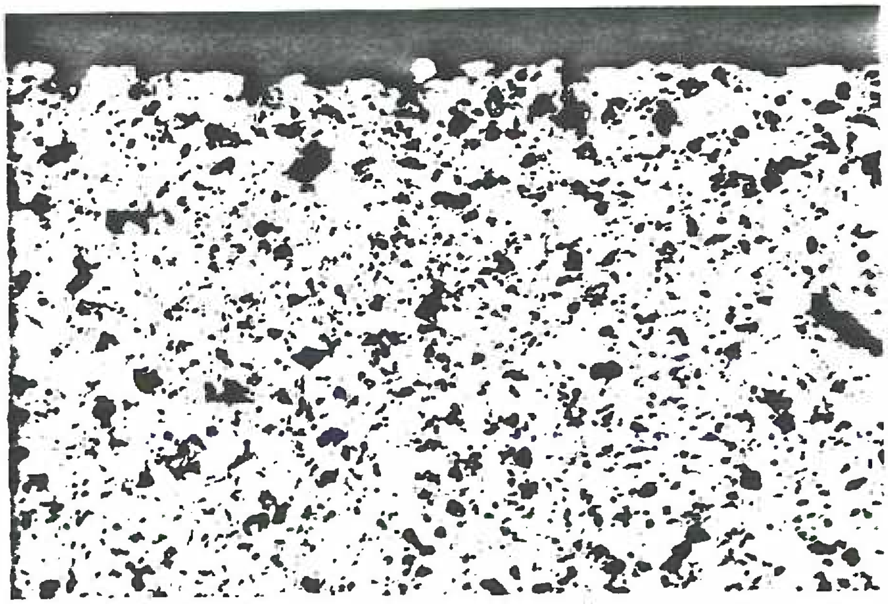
Plastic Tooth With Class II Cavity Preparation

Figure II



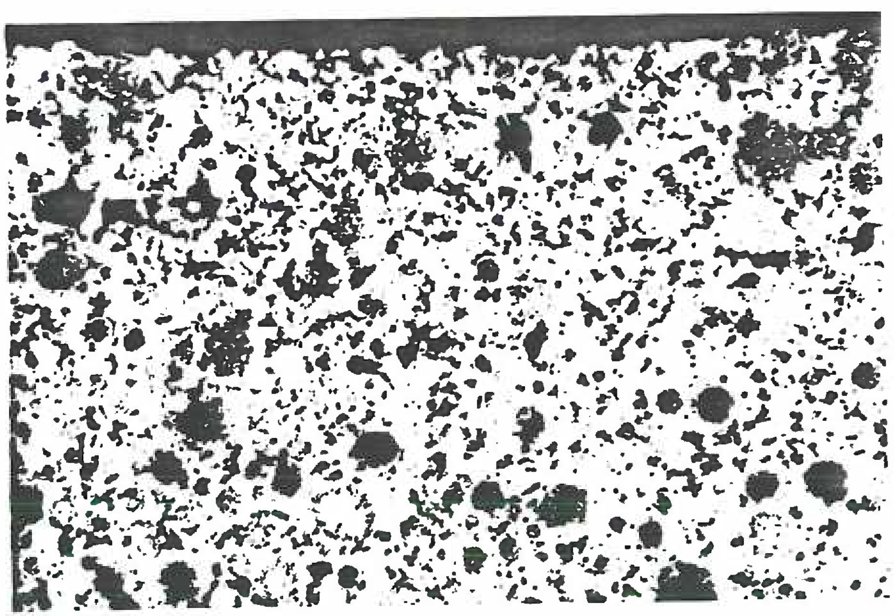
Dispersalloy (180X)
53% Pre-Condensation Mercury

Figure III



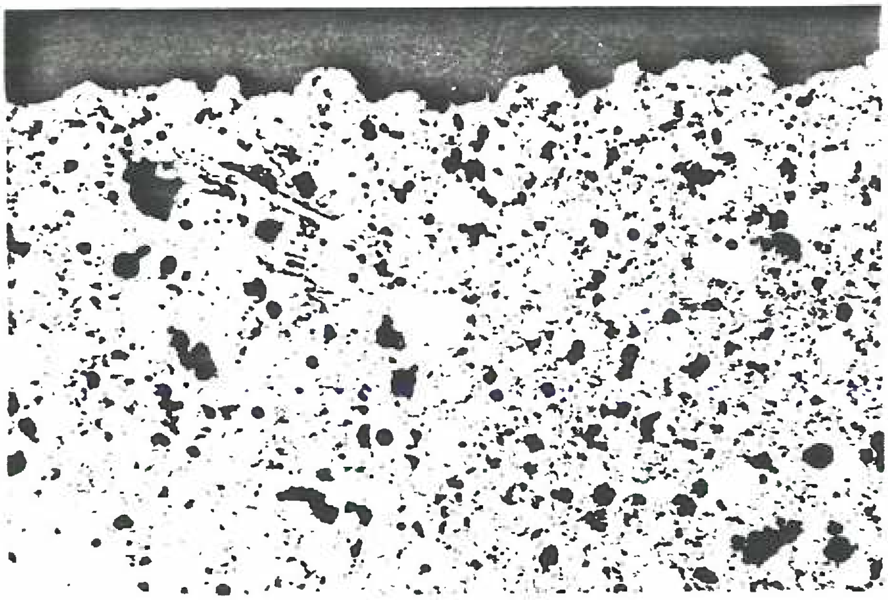
Aristaloy (180X)
55% Pre-Condensation Mercury

Figure IV



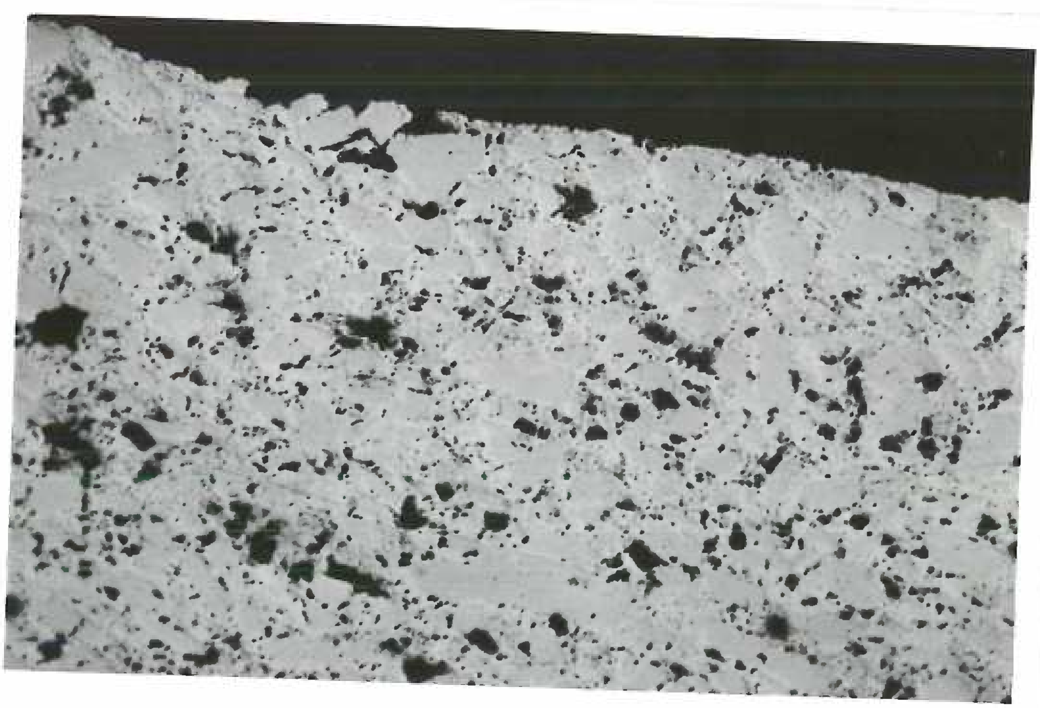
Spheraloy (180X)
48% Pre-Condensation Mercury

Figure V



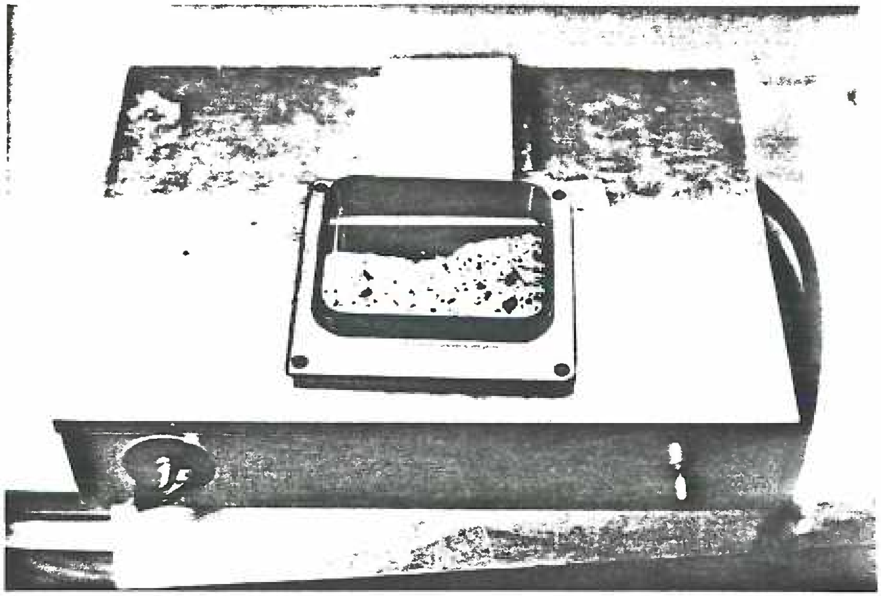
Tytin (180X)
43% Pre-Condensation Mercury

Figure VI



New True Dentalloy (180X)
51% Pre-Condensation Mercury

Figure VII



View Box with Photograph in Place

Figure VIII

Marginal Porosity versus Pre-Condensation Plasticity

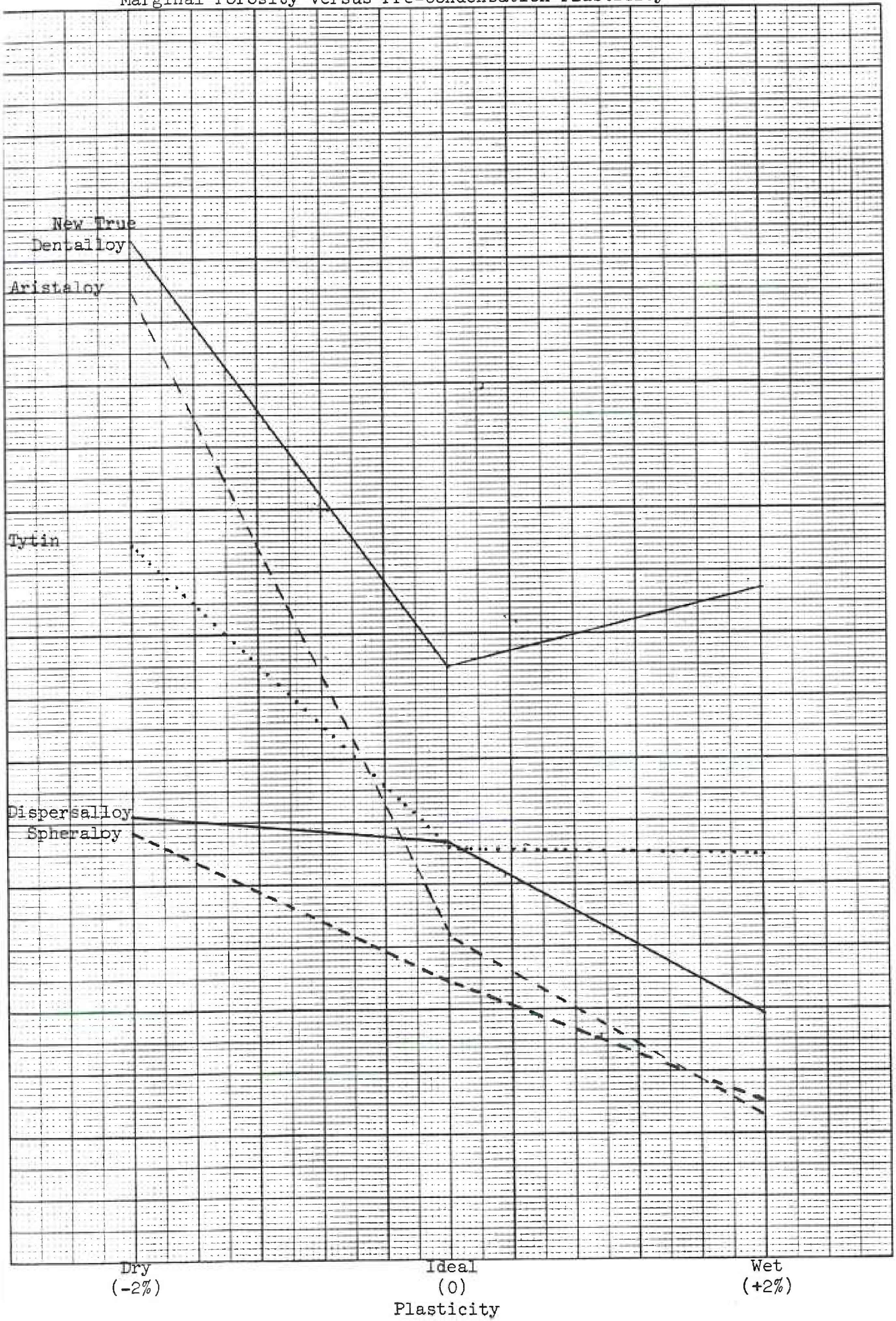


Figure IX

Marginal Residual Mercury versus Pre-Condensation Plasticities