A STUDY OF THE FACTORS AFFECTING THE PERFORMANCE OF ORGANIC COATINGS ON ALUMINIUM PRETREATED WITH BONDERITE 1415 AND BONDERITE 1414.

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ABSTRACT

A STUDY OF THE FACTORS AFFECTING THE PERFORMANCE OF ORGANIC COATINGS ON ALUMINIUM PRETREATED WITH BONDERITE 1415 AND BONDERITE 1414

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The purpose of this study was to investigate the temperature range over which failure of a paint film on aluminium surface occurred, when the surface had been pre-treated with Bonderite 1415, or with Bonderite 1414. These Bonderites produce a uniform coating which improves adhesion, inhibits corrosion and increases the durability of paint finishes.

Also investigated was the effect of a number of chemicals (e.g. acids, bases) on the adhesion of paint to the aluminium surface. Finally, a workable temperature range has been suggested. Various equations relating variables like peak metal temperature, oven temperature, residence time, etc., have been developed.

ACKNOWLEDGEMENT

The author wishes to express his sincere appreciation to Dr. B. Pant for his valuable guidance throughout the investigation.

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The author also wishes to express his appreciation to Hunter Douglas Co. of Canada, for providing various materials and facilities in their laboratories.

To my wife.

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1. INTRODUCTION

The corrosion of metals is a major source of failure of metallic structures. This problem may be envisaged as a reaction between a metal and its environment which results in an intermediate phase of an oxidized character. The control of the corrosion reaction is achieved by means of the so-called "surface treatments".[1-3]

The proper choice of a coating material, for such treatments, depends upon appearance and/or ease of application, as well as on the service performance.

Discussed in this thesis is the use of paints as coating materials for aluminium panels.

Such treatments normally involve three processes:

a) cleaning

b) chemical conversion coating

c) organic finishing

1.1 Cleaning

The first cleaning or precleaning stage is usually the removal of surface grease and oils. This is performed either by solvent or vapor degreasing, or by emulsion cleaning.

Generally, solvent degreasing is performed in tanks which contain boiling solvents. A wide variety of solvents is available for vapor degreasing.[4] The most common of these is trichloroethylene, which has the following characteristics: good solvent performance, high vapor density, non-flammability, good stability and a low boiling point. Fluorocarbons are also employed for vapor degreasing.[4] Solvent degreasing does produce a chemically clean surface but is usually supplemented by alkaline cleaners.

Emulsion cleaners usually consist of an aqueous soap solution[6], often operated at elevated temperatures. The function of emulsion cleaning is similar to that of vapor degreasers. They have the advantage of dealing rather more effectively with solid dirt and water soluble materials, such as soaps and sulphonated oils. Agitation may be used, either by air or by steam jets, and this helps to keep the grease in an emulsified condition. It also helps to prevent redeposition of loose oil on the metal surface.[5]

The first stage of cleaning must be followed by a hot alkaline cleaner, which generally is based on the hydroxides, carbonates, phosphates, both simple and complex, and the various silicates of sodium. This operation is generally performed in two stages. First, the items are soaked in the hot alkaline solution to remove residual grease and oil by emulsification and saponification. Second, a rinsing process follows which is as important as the cleaning process itself. The rinsing process may be performed either in cold or hot water, the latter having the advantage of keeping the structure open to permit removal of cleaning compounds and entrapped, emulsified oil.

As aluminium is readily attacked by alkaline solutions, the alkaline cleaner needs to be strictly controlled, and must satisfy the following conditions:

1. the salts should be easily and completely soluble.
2. the cleaner should be stable and possess good rinsing properties.

3. the alkalinity should be relatively low, preferably between pH 9 and pH 11.
4. it should have a high emulsifying power.
5. it should possess good wetting power.
6. the cleaner should be inhibited to minimize any attack on the base metal.
7. it should be able to deflocculate dirt particles and disperse them throughout the solution by colloidal action.

The function of the inhibitors in alkali cleaning is to provide a protective film (formed by reaction of the inhibitor with aluminium or the oxide surface). Thus care must be taken to avoid the formation of a too tenacious film, which would appear as visible etching. Depending on the type of surface required, it is possible to formulate and use either etching or non-etching alkaline cleaners.

Another important characteristic of the alkaline cleaners is their wetting power. The wetting of the contaminant is as important as the wetting of the metal surface. Generally alkalis are poor wetting agents, and water does not wet oils, so it is necessary to add wetting agents, so that the surface tension of the solution is reduced to a value similar to that of the contaminant. So, in the presence of wetting agents, surface oils are removed quickly and an increased penetration of the cleaner is obtained. They also have an air emulsifying action, preventing the redeposition of oil and keeping it suspended for long periods of time.

The use of soaps as wetting agents should be avoided, since they tend to form insoluble metal soaps. Numerous wetting agents are available and a complete list, including detergents, emulsifying and rinsing agents, may be found in the literature.[7]

1.2 Chemical Conversion Coatings

The second step on the aluminium surface treatment is the application of chemical conversion coatings which act as undercoatings and as bases for organic finishing.[8,9]

There are several methods of chemical conversion which are based essentially on the formation of an oxide film on the metal surface.[10,11] The thickness of this film depends on the alloy composition and on the time of exposure. In general an ideal protective coating must possess the following properties:[10]

1. low solubility in water, acids and alkalis
2. resistant to mechanical injury such as abrasion or scratching.
3. bind readily with finishing materials.
4. should not electrolytically accelerate the attack on the base metal.

The most commonly used system is the chromate treatment.[12,13] Chromating of a metal involves the formation of a passivating metal oxide/chromium oxide film on the metal surface. The film is prepared throughattack of the metal by activators such as sulphates, nitrates, chlorides and fluorides which are contained in the chromium solution. Where attack occurs, some metal is dissolved, the resulting hydrogen reduces the chromate ion, and a film of Cr_2O_3, $CrO_3 \cdot H_2O$ or $Cr(OH)3$, $Cr(OH)$, CrO_4, is formed, (colour varies through yellow to olive drab depending upon its composition).

This film is deposited on the metal surface unless the solution is sufficiently acidic to dissolve it as soon as it is formed. The film also contains the oxide of the metal being treated. The colour variation arises from the proportion of Cr^{VI} in the film, clear chromate films having little Cr^{VI}, but large amounts are present in the irridescent yellow and olive drab films. The protective action of the chromating coating is due to the Cr^{VI} and Cr^{III} present in the film. The treatment is achieved by using either chromic acid (CrO_3) or potassium dichromate ($K_2Cr_2O_7$) and the time of application ranges from a few seconds to minutes depending on the required film thickness. The various reactions are as follows:

$$Al \longrightarrow Al^{3+} + 3e^-$$

$$3H_2O + 3e^- \longrightarrow 3OH^- + \frac{3}{2} H_2$$

$$2Al^{3+} + 6OH^- \longrightarrow Al_2O_3\, n\, H_2O + (3-n)H_2O$$

$$(n = 0 - 3)$$

Then the chromic acid is oxidized by one of the following mechanisms:

$$2CrO_4^{-2} + 3H_2 \longrightarrow Cr_2O_3 + 4OH^- + H_2O$$

$$CrO_4^{-2} + 3/2\ H_2 \longrightarrow CrO.OH + 2OH^-$$

$$CrO_4^{-2} + 3/2\ H_2 + H_2O \longrightarrow Cr(OH)_3 + 2OH^-$$

One of the principal benefits of the conversion coating is to prevent the spreading of corrosion if the organic coating is damaged.

On the other hand as all organic films are to some degree permeable to moisture,[14] it is advisable to use a previous surface conversion coating such as a chromate dip, especially for active metals such as aluminium.

At present many processes employ solutions containing ferrocyanide or mixtures of ferricyanide[15], or phospho-O2-[16] silico-molybdic acids.

1.3 Organic Finishing

A paint may be described as a continuous organic polymeric film that is applied to a variety of substrates. All paints contain a binder, which is the continuous film-forming component or phase. The binder may be a natural oil or resin or component of alkyd varnish. It may be a resin such as methacrylate or a vinyl compound. A solvent is usually required for the binder so that it is sufficiently mobile to be conveniently applied to the substrate. Other paint systems may utilize a dispersion medium such as water or certain organic solvents to carry the binder as a dispersed phase. This dispersion medium is called the paint vehicle. Two types of water paint vehicles are used; those involving resin dispersion or emulsion, and those containing water-soluble resins.

Emulsion paints contain binders produced by polymerisation, co-and ter-polymerisation of monomers, such as vinyl chloride, vinyl acetate, styrene-butadiene, etc. These products are dispersed in an aqueous medium (emulsion).

Water-soluble resins are prepared by copolymerisation of acrylic or methacrylic acid with vinyl or other acrylic monomers such that the polymer contains carboxylate groupings which can then be reacted with a base to become water soluble.

Many water-soluble polymers are known, notably carboxymethyl cellulose and polyvinyl alcohol, although these polymers retain their water solubility after film formation. Other resins, that are initially water-soluble become insoluble upon film formation.

Generally, water-based paints are less stable than typical organic solvent-based paints. When used in the metal finishing industry, especially with emulsion paints, a rigorous consistency in formulation is required, otherwise performance differences could arise.

Paints also contain pigments, extenders and additives. Pigments are added to the paint vehicles to confer aesthetics characteristics, colour, and to improve physical properties and/or to provide corrosion protection to the film.[17,18]

Extenders are usually inorganic compounds such as minerals or salts of calcium, barium, magnesium and aluminium which increase the 'body' of the paint. Extenders are used to modify the properties of both the liquid paint and the dried film, but generally do not contribute to the colour of the paint.

Additives are included in paint formulation to impart specific properties to the vehicle or achieve particular effects in the final film. The most important additives are plasticisers, wetting agents, driers, fungicides, flow-controlling agents, stabilisers and metallic soaps.

Generally, the choice of a paint as a finishing coat is made so as to increase the resistance of the metal to corrosion and/or to improve its appearance. Corrosion occurs on the metal surfaces, because of their lack of homogeneity. This lack of homogeneity furnishes the points of origins of electrochemical forces, which lead subsequently to the formation of anodic and cathodic points. The organic binding medium in a paint by its very nature retards ionic conductance. Therefore, the function of a paint must be to isolate the metal surface for relatively long periods, if it is to provide protection against corrosion. Good adherence is therefore desired.

The adhesion of an organic coating to metal surfaces may be chemical or physical in nature. Chemical adhesion is defined as adhesion between surfaces which are held together by valence forces, or by the same type of force that gives rise to cohesion, Physical adhesion is defined as the adhesion between surfaces in which the parts are held together by interlocking action.

Chemical adhesion is due to primary bonds (e.g. covalent , electrostatic or metallic) as well as to weaker Van der Waals forces.[16]

The failure of chemical bonds may be due to: 1) low bond strength at the interface, leading to separation of the coating from the metal; 2) high bond strength leading to cohesive failure in the coating polymer, or 3) a combination of the two.[19]

The inherent strength of the bond between metal and coating may depend upon both the physical and chemical nature of the surface, as well as upon the composition of the coating material and the changes that occur upon curing, drying and aging. Thus it is very important to have the aluminium surface completely free from contaminants such as oils, greases, soils, etc., because all these materials interfere seriously with adhesion of organic coatings. It is also very important to use chemical conversion treatments prior to the application of the organic coatings in order to minimize the influence of paint-metal reactions on adhesion. These latter tend to reduce adhesion to the paint, so that the finish may form blisters or peel off.

One of the most common reasons for poor adhesion is the permeability of the paint to water.[20-25]

This process is complex and affected by the vapor pressure across the paint film, diffusion of water in the film, thickness, area, and physical structure of the film.

The effect of water absorption on the film is not clear.[20] There is no clear-cut relationship between the amount of water that permeates and the amount that is absorbed.[20] Thus, some organic materials may absorb very small quantities of water, but may permit diffusion of considerably more through them. The reverse of this action may also be observed.

The performance of an organic coating in the protection of metals depends, therefore, on the character of the metal surface (cleanness), the composition of the paint, thickness, adherence, and continuity of the coating, moisture absorbing characteristics, and the nature of the environment.

The organic finish[13] is composed of a primary (primer coat) and a secondary (top coat) paint layer. The application of the primer is essential for aluminium, unless it is to be used under only mildly corrosive conditions. The primer is the bonding coat and it should possess adhesion and flexibility. It invariably contains metallic inhibitive pigments.[26] For the top coat layer, pigmentation and adhesion are less important factors, and they can be chosen, depending upon the drying system being used (air drying or baking finishing). The paint must have inherent chemical and weathering resistance so that the top coat provides an additional protection to the substrate. A wide variety of finishes such as smooth glass finishes, metallic lustres, wrinkled finishes, hammered effects, and other special finishes may be achieved by a careful selection of the many combinations and permutation available.[27]

2. EXPERIMENTAL

2.1 Materials

Aluminium plates were pretreated either with Bonderite 1415 or Bonderite 1414. Bonderite is a Trademark of the Parker Rust Proof Co., for the chemical conversion coatings (chromate system) used on aluminium. Thermopapers (papers sensitive to heat), paints and rollers were obtained from the Hunter Douglas Co. of Canada.

2.2 Oven

In order to ensure reproducibility with the industrial situation, the oven used was of the forced air circulation type. The reason for this procedure was because the paint during line production, is cured by the blowing of hot gas from below and exhaust and recycle from above the metal surface. Furthermore, a solid aluminium block (16 cm length X 15 cm width, and 2,5 cm thickness, containing five grooves each of 15 cm length X 1 cm depth X 0.5 cm width), was used to support the plate. The block was designed in such a way so as to allow a minimum plate surface to touch the block and at the same time allow the plate surface to be almost fully exposed to the hot air. The oven temperature (OT) was measured by a Doric Trendicator 410A, using a copper-constantan thermocouple. The uncertainty of the temperature reading was $\pm 1^{0}$C. The Fisher Isotemp, Model 350 oven had an accuracy (relative to the temperature) of $\pm$ 2.0 ^{o}C, a reproductibility of $\pm$ 2.0 ^{o}C and a resolution of 1.0 ^{o}C and a temperature range of 40 ^{o}C to 300 ^{o}C. The plate temperature, or peak metal temperature (PMT), was measured by heat sensitive tapes or thermopapers. The uncertainty of the thermopapers was in the order of $\pm$ 5.5 ^{o}C (10 ^{o}F).

2.3 Paint Application

The paint was applied by the use of rollers. The use of rollers has the advantage of being very economical, rapid in operation and provides good surface coverage.

Basically two different types of rollers were used. One of them was used for the primed metal (consists of the bare metal plus the Bonderite Pretreatment plus the primer coat), and the other for the top coat (consists of the primed metal plus the top coat layer). The main difference between them is the film thickness that can be achieved. For the primer, Roller No.12; and for the top coat Roller No. 28; were used. These corresponded to film thicknesses of 0.10 - 0.15 mm and 0.90 - 0.95 mm respectively.

A uniform coating of the paint was achieved by applying a uniform pressure on the roller and at the same time spreading the paint all over the plate with one stroke only.

In this project, attempts have been made to study the resistance of the pretreatments and paint systems to waters of different pH values. The following method was used to determine the film failure. The baked plates were soaked in water for a period of time (from 17 to 24 hrs). The adhesion was then measured by attaching and then removing an ordinary adhesive tape (e.g. scotch tape). The peeling or removal of small amounts of paint from the metal surface to the tape indicated failure.

2.4 Mechanical Tests

In order to verify the mechanical condition of the film for both primer and top coat, a series of tests were conducted on the plates. These tests were carried out at the laboratories of the Hunter Douglas Co. They included:-

a) Bend test.

b) Ball test.

c) MEK rubs.

d) Thickness measurements.

a) The Bend Test consists of the bending of a painted plate, followed by the application and removal of an ordinary adhesive tape on the resulting edge of the bent plate. The film is considered a failure when small amounts of paint remains adhered to the tape.

b) The Ball test consists of the application of an impact force of 30 in/lb upon the plate. As a result of this impact, an indentation is formed on which an adhesive tape is applied; as it was in the case of the Bend test, the film is considered to be a failure if some paint adhered to the tape after its removal.

c) The MEK (methyl ethyl ketone) rubs are applied to both primer and top coat film paints. The film paint is considered to be satisfactory where the number of rubs to remove the paint is equal to or greater than 15.

d) Film thickness measurements were carried out by means of a Permascope Thickness gauge previously calibrated on a standard surface of 1.42 mm.

3. RESULTS AND CONCLUSIONS

3.1 Primed And Top Coated Metal

The first problem investigated was the temperature range over which failure of a primer film surface occurred, when the sample had been pre-treated with Bonderite 1415 or with Bonderite 1414.

Tables 4.1.2 to 4.1.3 contain results with Bonderite 1415 as the pre-treatment, Tables 4.1.4 to 4.1.6 contain the results obtained with Bonderite 1414 as the pre-treatment. It was difficult to ensure exactly equal oven temperatures for the two different pre-treatments; this was due simply to the technique used in placing the samples in the oven. However, the slight descrepancies in the two sets of tests were not considered significant.

For both pre-treatments, the test of success was the water soak test.

The terms that appear on the tables are explained as follows:

Extent of failure (degree of film peeling)

O.T.: Oven temperature in ^{o}F and ^{o}C

P.M.T. peak metal temperature (refers to the highest metal temperature) in ^{o}F and ^{o}C.

R.S.: residence time in seconds

Soaking time: in water (hrs).

Tables 3.1.1 shows a summary which relates the peak metal temperature (PMT) at which the primer film fails, as described by the water soaking test, against its corresponding residence time in the oven.

Table 4.2.1 through 4.2.6 were obtained using samples which had been pre-treated (i.e. with Bonderite 1414, or 1415) and primed, on the assembly line of the Hunter Douglas Co., However, the top coats were applied by the author.

The results of Table 3.1.1 appear to substantiate the results obtained in Table 3.1.2 although in one case the primer coat was tested, while in the other case the primer plus the top coat were tested.

TABLE 3.1.1

SUMMARY OF OT, PMT AND RS AT WHICH FAILURE OCCURED

Surface: Primed metal

Pretreatment	O.T. °F(°C)	PMT °F(°C)	R.S. (s)
Bonderite 1415	502(261)	370(188)	40
	453(234)	351(178)	50
	414(212)	340(171)	60.
Bonderite 1414	499(259)	No failure on entire range.	
	460(238)		
	410(210)		

TABLE 3.1.2

SUMMARY OF OT, PMT AND RS AT WHICH FAILURE OCCURED

Surface: Primed and top coated metal

Pretreatment	O.T. °F(°C)	PMT °F(°C)	R.S. (s)
Bonderite 1415	500(260)	368(186)	40
	450(232)	350(182)	50
	408(209)	343(173)	60
Bondertie 1414	498(259)	No failure in entire range.	
	455(235)		
	421(216)		

3.2 Curve Analysis And Discussion

Figures 4.3.1 to 4.3.5 represent the plots of peak metal temperatures vs the residence times for the five oven temperatures. (data in Table 3.2.1). Figures 3.2.1 through 3.2.5 represent the plots of peak metal temperatures vs the logarithm of residence times. (data in Table 3.2.1).

The method used for calculations was that of linear regression. (least square method).

Also in Table 3.2.1 is shown the experimental data from which Equations 3.2.1 to 3.2.5 were obtained.

This table is the result of the averaging of the values presented in Tables 4.1.1 to 4.1.6; 4.2.1 to 4.2.6; 4.4.1 to 4.4.10; 4.5.1, 4.5.2, 4.5.6, 4.5.7, 4.5.11, 4.5.12, 4.5.16, 4.5.17, 4.5.21, 4.5.22, 4.5.28, 4.5.29, 4.5.32 and 4.5.33.

TABLE 3.2.1

EXPERIMENTAL DATA (AVERAGE)

OT °F(°C)								
412(211)	PMT(°F)	326	347	355	385	400		
	RS (s)	50	60	70	100	130		
455(235)	PMT(°F)	290	338	370	375	420	423	
	RS (s)	30	50	60	70	100	130	
499(259)	PMT(°F)	317	370	401	441	454	468	
	RS (s)	30	40	50	70	90	130	
600(316)	PMT(°F)	310	340	360	390	405	420	465
	RS (s)	15	17	20	24	25	27	40
700(371)	PMT(°F)	340	410	500				
	RS (s)	12	17	28				

By applying the linear regression method, the following equations are obtained:
(See figures, 3.2.1 through 3.2.5).

OT

$412^{o}F$ ($211^{o}C$)	$PMT = 30.637 + 76.392 \ln RS$	3.2.1
$455^{o}F$ ($235^{o}C$)	$PMT = -32.668 + 95.986 \ln RS$	3.2.2
$499^{o}F$ ($259^{o}C$)	$PMT = -11.612 + 102.392 \ln RS$	3.2.3
$600^{o}F$ ($316^{o}C$)	$PMT = -113.875 + 159.094 \ln RS$	3.2.4
$700^{o}F$ ($371^{o}C$)	$PMT = -126.142 + 188.250 \ln RS$	3.2.5

And the corresponding estimator factors are shown in Table 3.2.2. The estimated values based on equations 3.2.1 to 3.2.5 are shown in Table 3.2.3. The corresponding curve is shown in Figure 3.2.6.

TABLE 3.2.2

ESTIMATOR FACTORS

Oven temperature °F(°C)	Intercept (m)	Regression coefficient (slope) (b)	Coefficient of determination (r^2)
412(211)	30.637	76.392	0.989
455(235)	- 32.668	95.986	0.970
499(259)	- 11.612	102.392	0.926
600(316)	-119.875	159.094	0.983
700(371)	-126.142	188.250	0.999

TABLE 3.2.3

ESTIMATED PEAK METAL TEMPERATURE (PMT) USING EQUATIONS 3.2.1 TO 3.2.5

Oven temperature °F (°C)												
412(211)	△	PMT (°F)	277	290	312	330	343	355	382	402		
		RS (s)	25	30	40	50	60	70	80	90		
455(235)	▲	PMT (°F)	276	294	321	343	360	375	409	435		
		RS (s)	25	30	40	50	60	70	100	130		
499(259)	◦	PMT (°F)	318	337	366	389	408	423	449	487		
		RS (s)	25	30	40	50	60	70	90	130		
600(316)	•	PMT (°F)	317	337	363	392	398	410	427	473	508	538
		RS (s)	15	17	20	24	25	27	30	40	50	60
700(371)	×	PMT (°F)	342	407	480	501	514	568	610	645		
		RS (s)	12	17	25	28	30	40	50	60		

FIGURE 3.2.1
PEAK METAL TEMPERATURE (PMT) VS THE NATURAL LOGARITHM OF RESIDENCE TIME (ln RS)

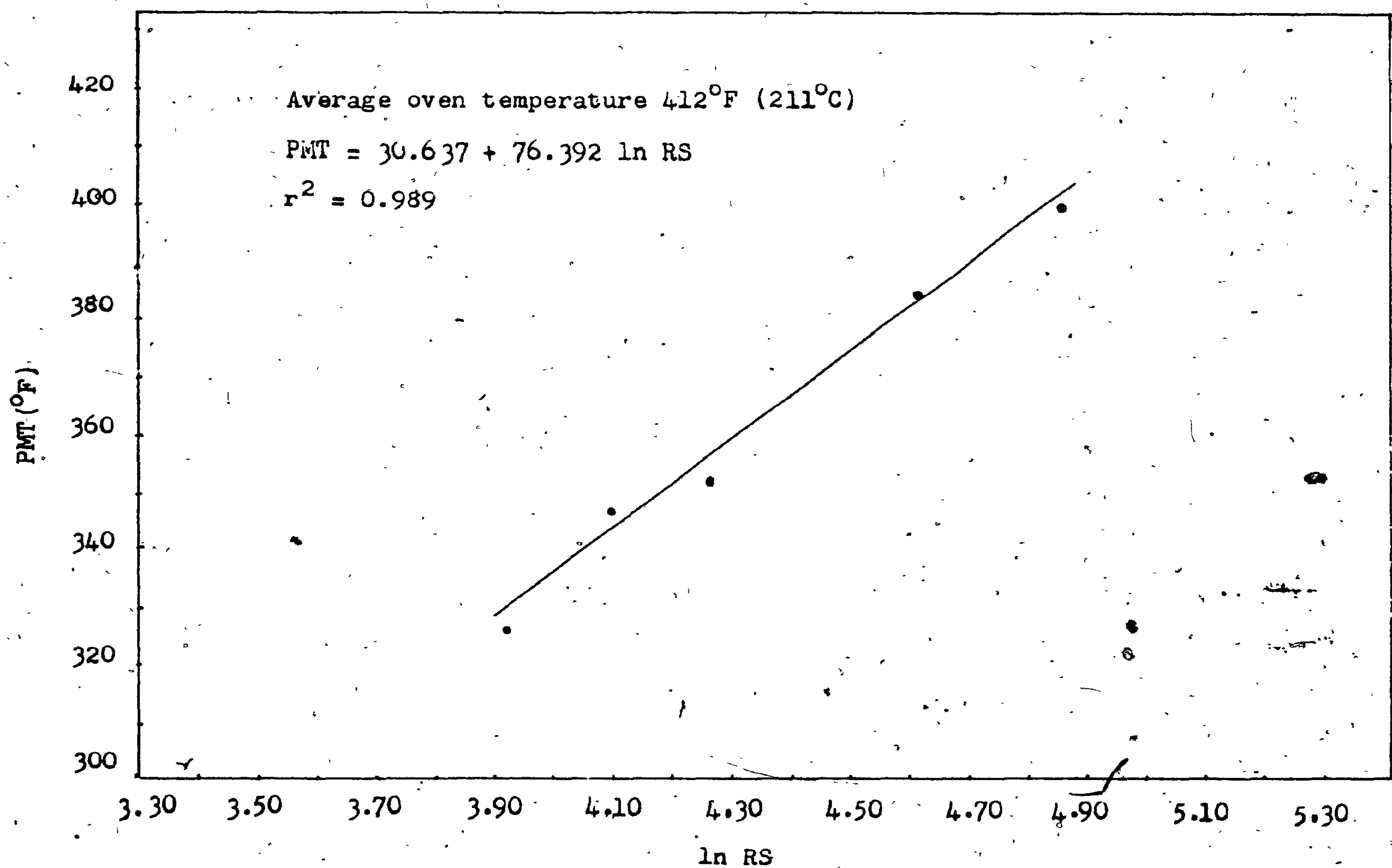


FIGURE 3.2.2
PEAK METAL TEMPERATURE (PMT) VS THE NATURAL LOGARITHM OF RESIDENCE TIME (ln RS)

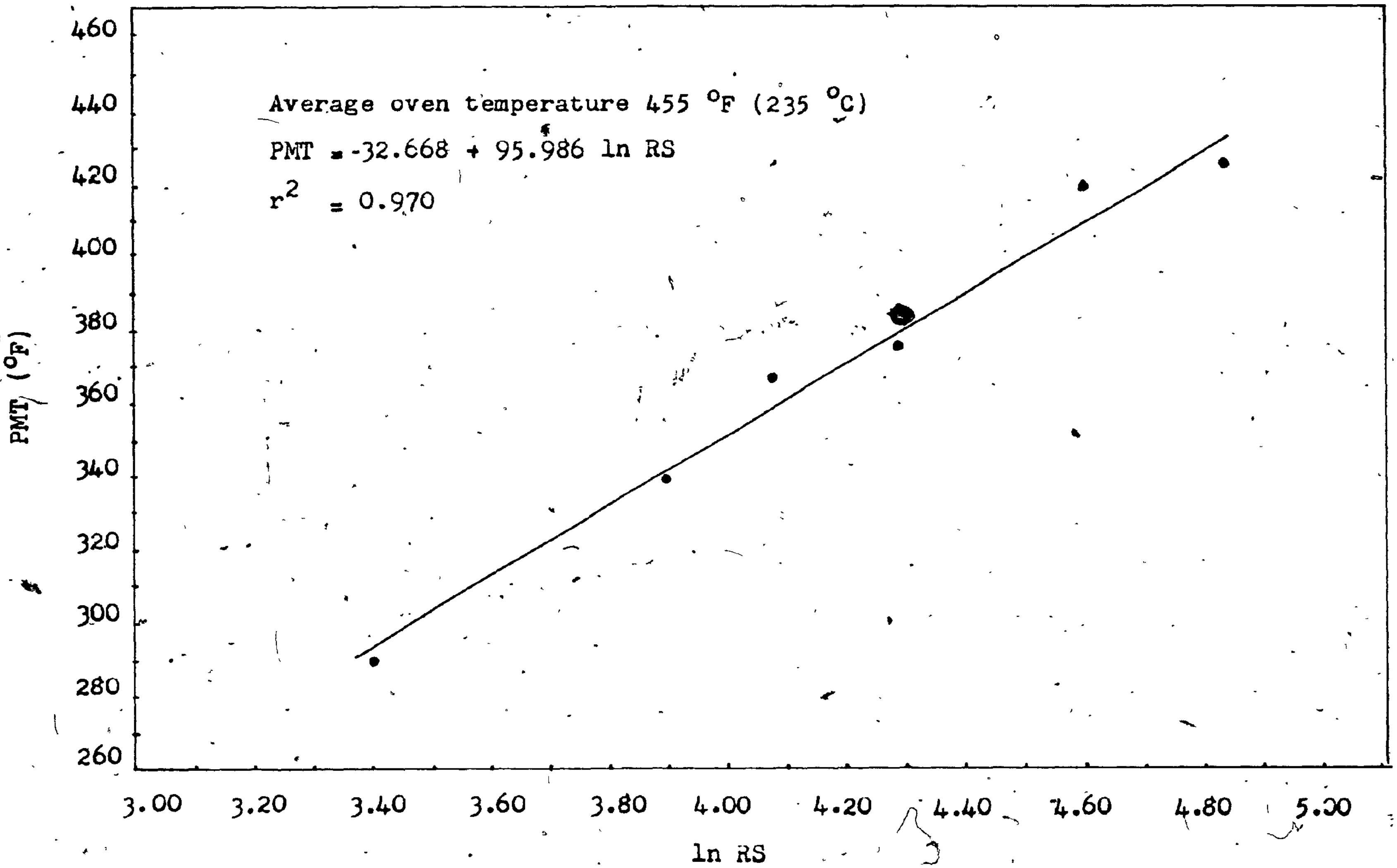


FIGURE 3.2.3
PEAK METAL TEMPERATURE (PMT) VS THE NATURAL LOGARITHM OF RESIDENCE TIME (ln RS)

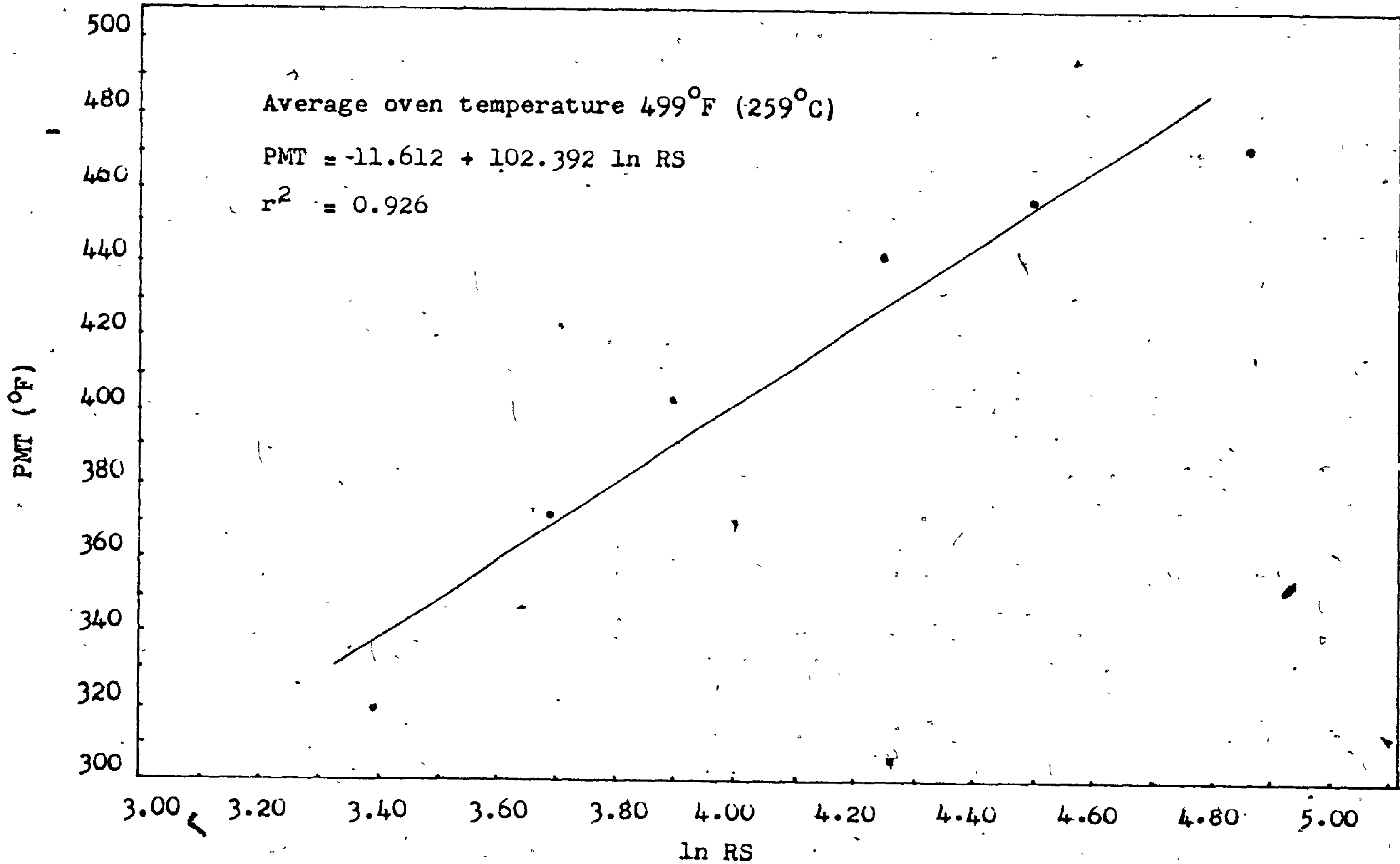


FIGURE 3.2.4

PEAK METAL TEMPERATURE (PMT) VS THE NATURAL LOGARITHM OF RESIDENCE TIME (ln RS)

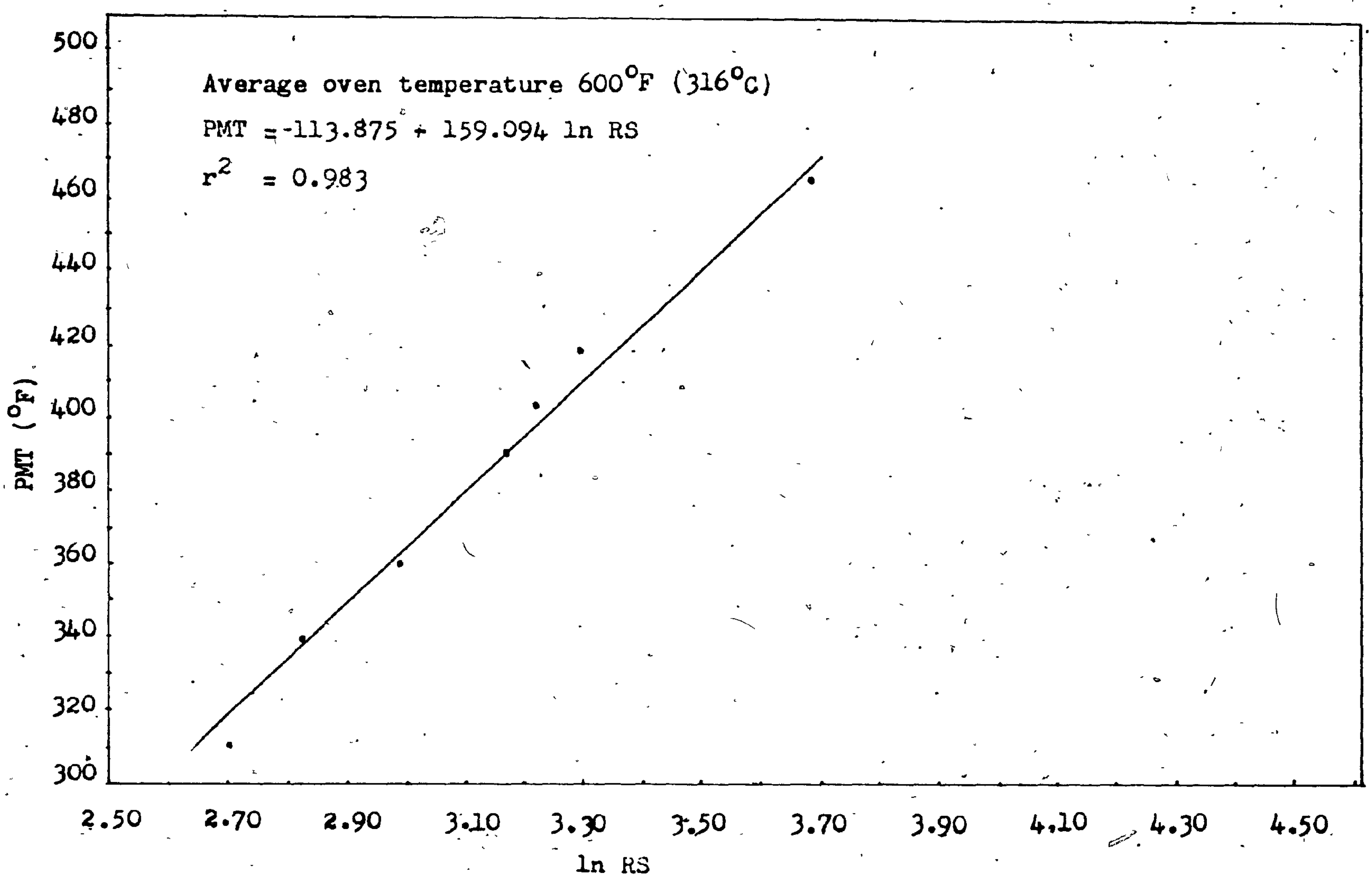


FIGURE 3.2.5
PEAK METAL TEMPERATURE (PMT) VS THE NATURAL LOGARITHM OF RESIDENCE TIME (ln RS)

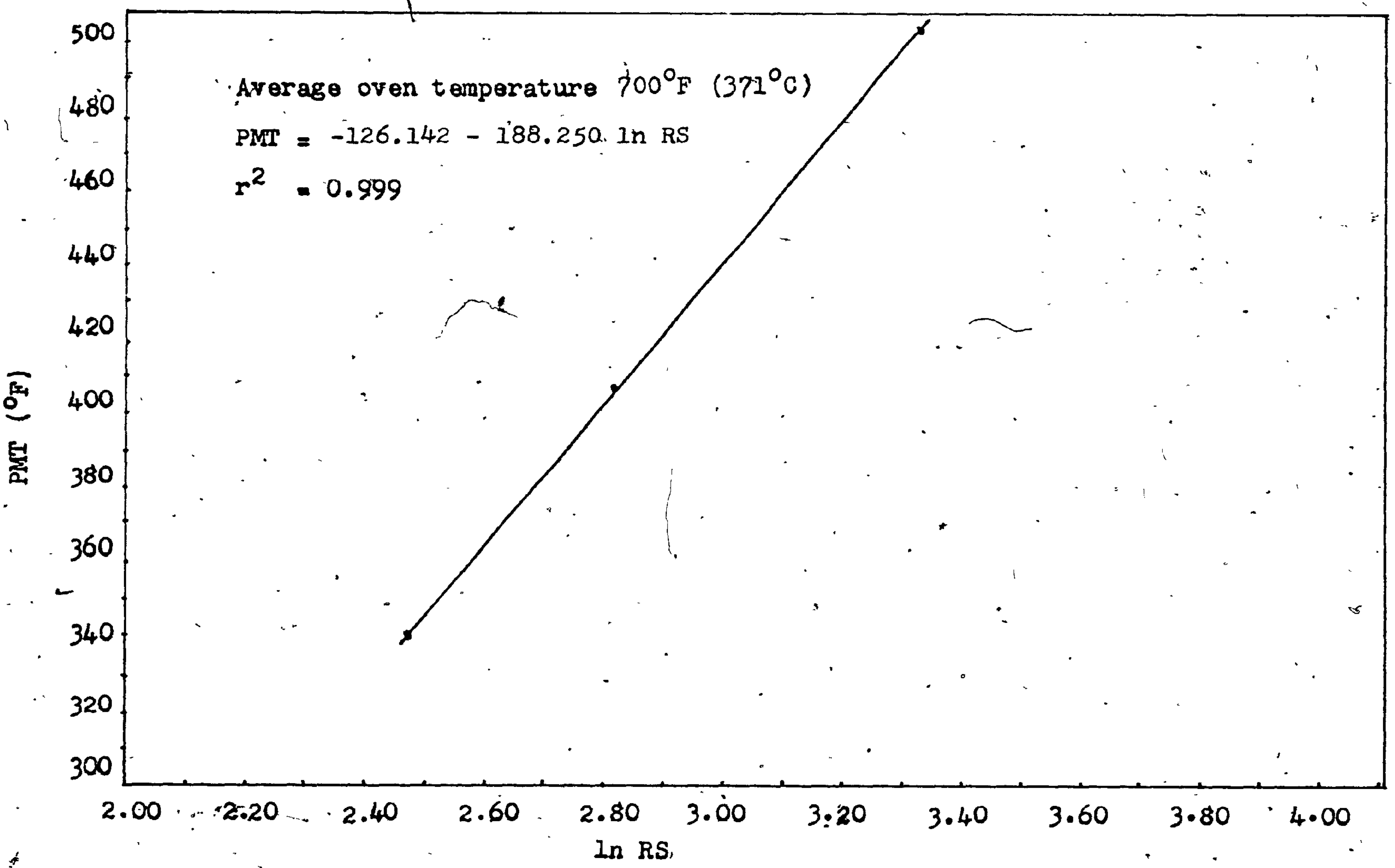
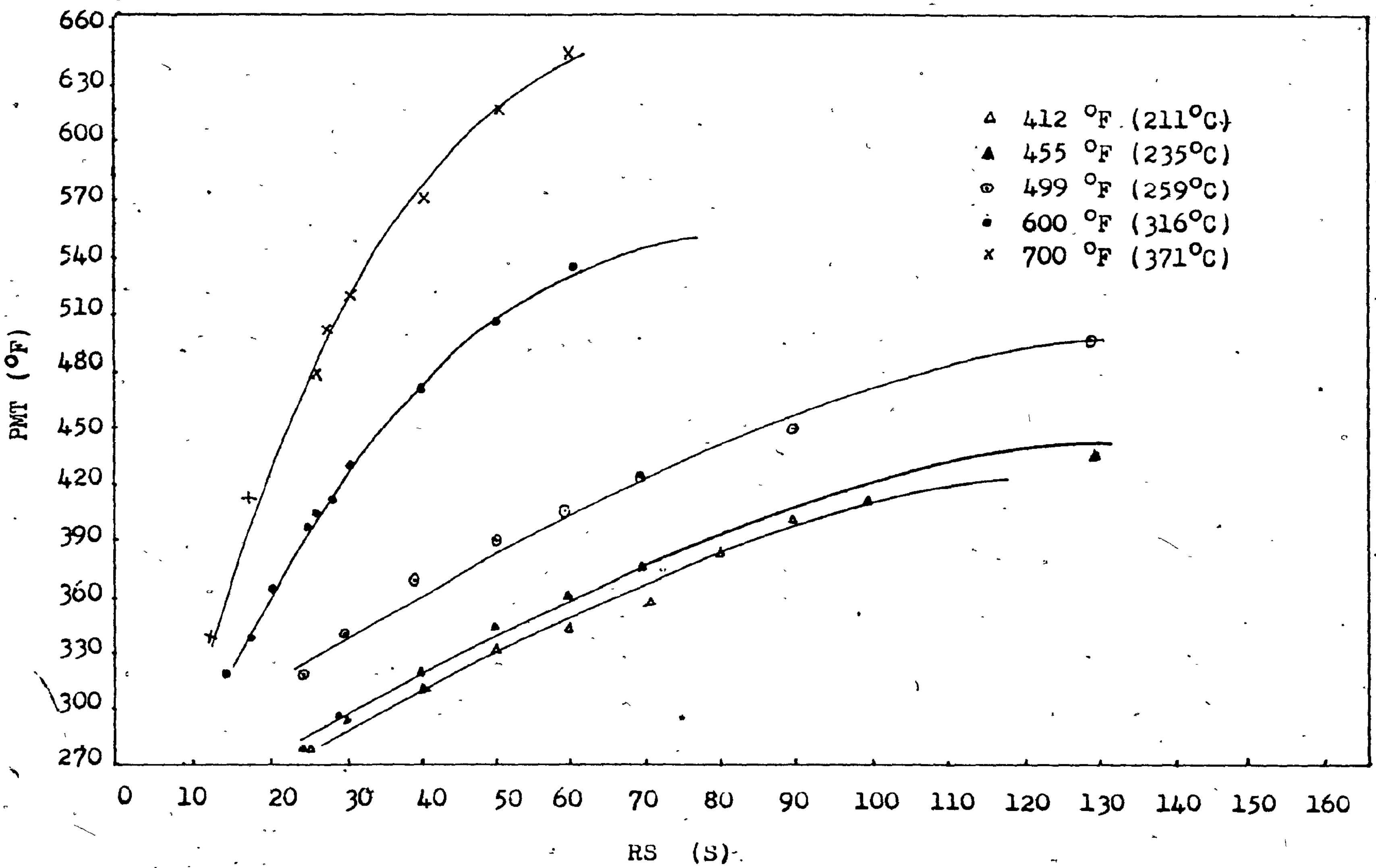


FIGURE 3.2.6
PEAK METAL TEMPERATURE (PMT) VS RESIDENCE TIME (RS)



In order to further explore the relationship between the three parameters, oven temperature, peak metal temperature and residence time, a series of equations were calculated using the linear regression method, and data from Table 3.2.4

Figures 3.2.7 to 3.2.11, show their plots, and the corresponding equations are:

For 25 sec	OT = 1.310 PMT + 75.159	3.2.6
For 30 sec	OT = 1.197 PMT + 87.398	3.2.7
For 40 sec	OT = 1.053 PMT +103.300	3.2.8
For 50 sec	OT = 0.963 PMT +113.423	3.2.9
For 60 sec	OT = 0.900 PMT +120.585	3.2.10

The estimator factors and estimated values are shown on Tables 3.2.5 and 3.2.6 respectively.

TABLE 3.2.4

ESTIMATED PEAK METAL TEMPERATURE (PMT)

USING EQUATIONS 3.2.1 TO 3.2.5

RS(S)	25	30	40	50	60
OT °F(°C)	PMT(°F)	PMT(°F)	PMT(°F)	PMT(°F)	PMT(°F)
412(211)	276.53	290.46	312.44	329.49	343.41
455(235)	276.30	293.80	321.41	342.83	360.33
499(259)	317.98	336.64	366.10	388.95	407.62
600(316)	398.23	427.24	473.00	508.50	537.51
700(371)	479.81	514.13	568.29	610.30	644.62

TABLE 3.2.5

ESTIMATOR FACTORS OF EQUATIONS 3.2.6 TO 3.2.10

Residence time(s) (RS)	Intercept (m)	Regression Coefficient (slope) (f)	Coefficient of determination (r^2)
25	75.159	1,310	0.981
30	87.398	1.197	0.984
40	103.300	1.053	0.987
50	113.423	0.963	0.989
60	120.585	0.900	0.990

TABLE 3.2.6

ESTIMATED OVEN TEMPERATURE (OT) VALUES

USING EQUATIONS 3.2.6 TO 3.2.10

RS	25	30	40	50	60
OT(°F)	437	435	432	431	430
	437	439	442	444	445
	492	490	489	488	487
	597	599	601	603	604
	704	703	702	701	701

FIGURE 3.2.7

OVEN TEMPERATURE (OT) VS PEAK METAL TEMPERATURE (PMT)

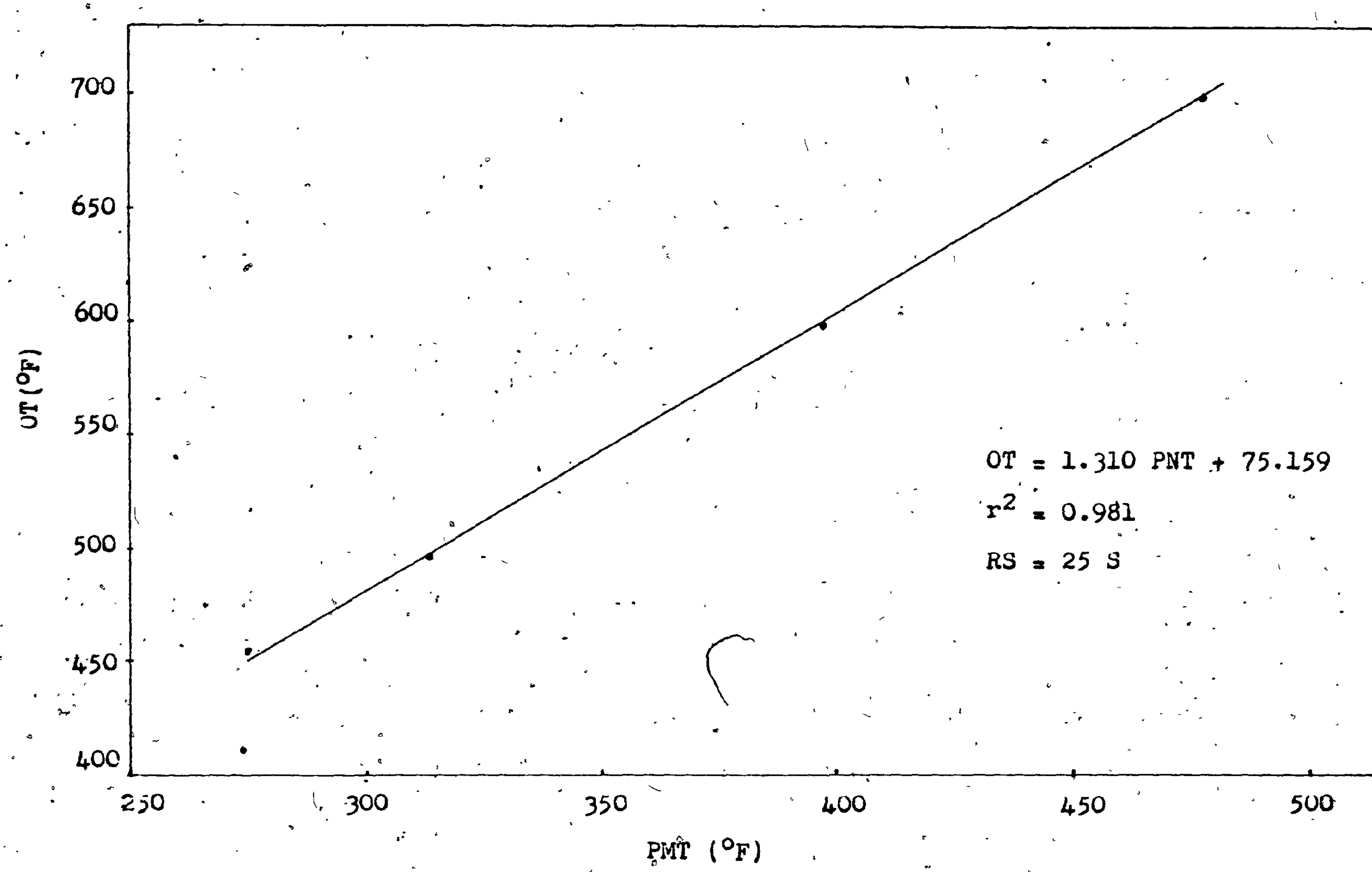


FIGURE 3.2.8

OVEN TEMPERATURE (OT) VS PEAK METAL TEMPERATURE (PMT)

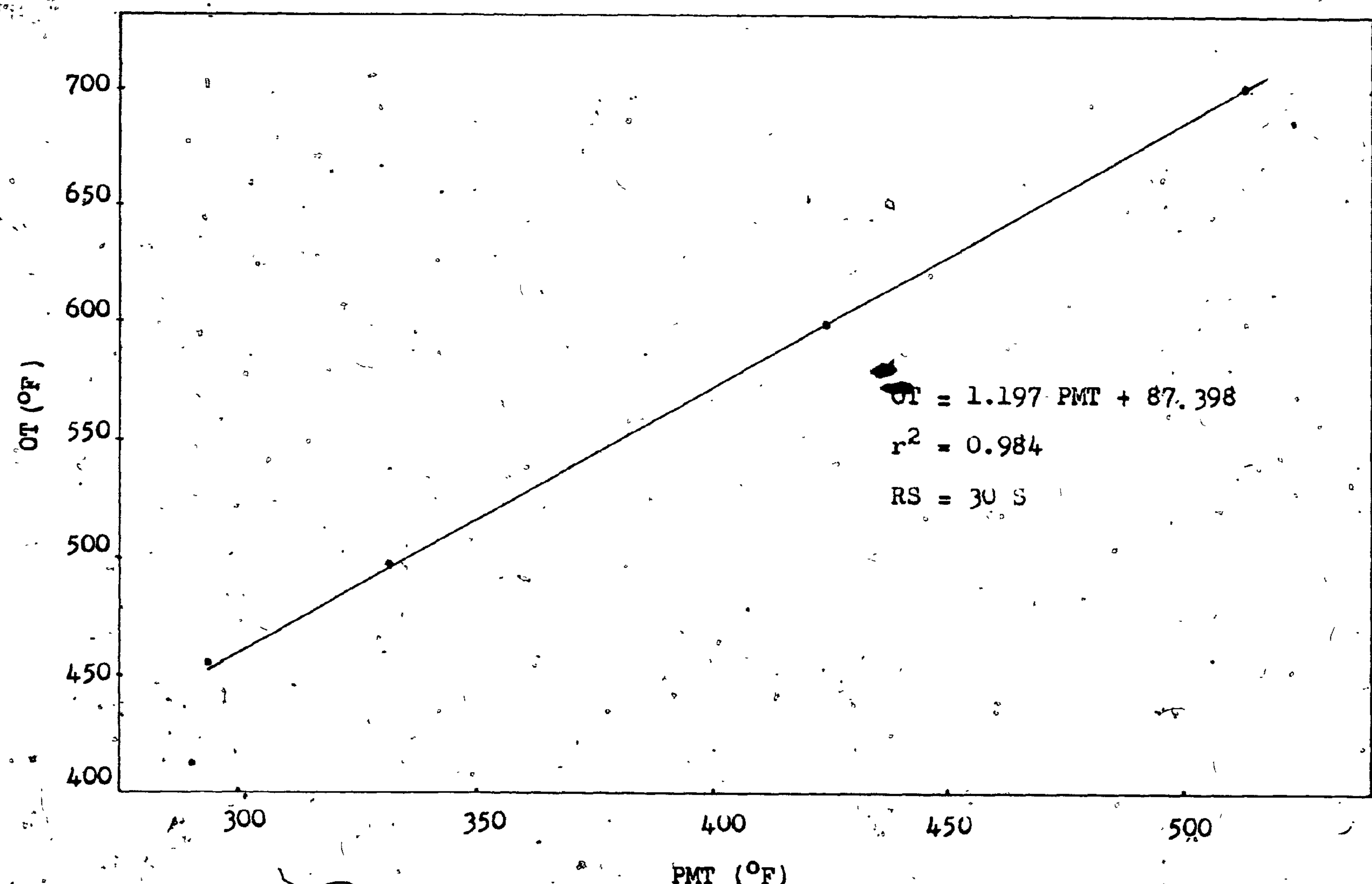


FIGURE 3.2.9

OVEN TEMPERATURE (OT) VS PEAK METAL TEMPERATURE (PMT)

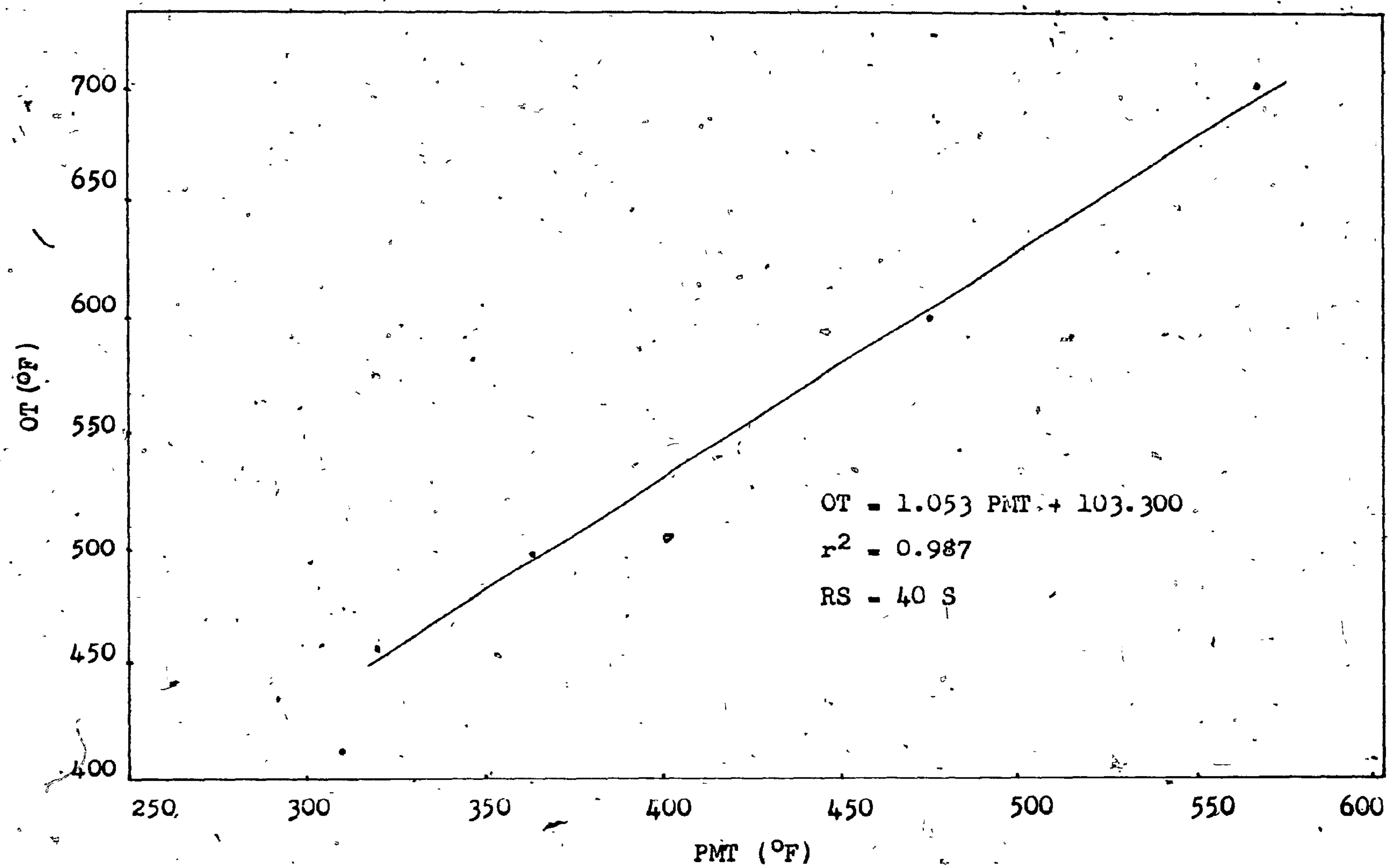


FIGURE 3.2.10
OVEN TEMPERATURE (OT) VS PEAK METAL TEMPERATURE (PMT)

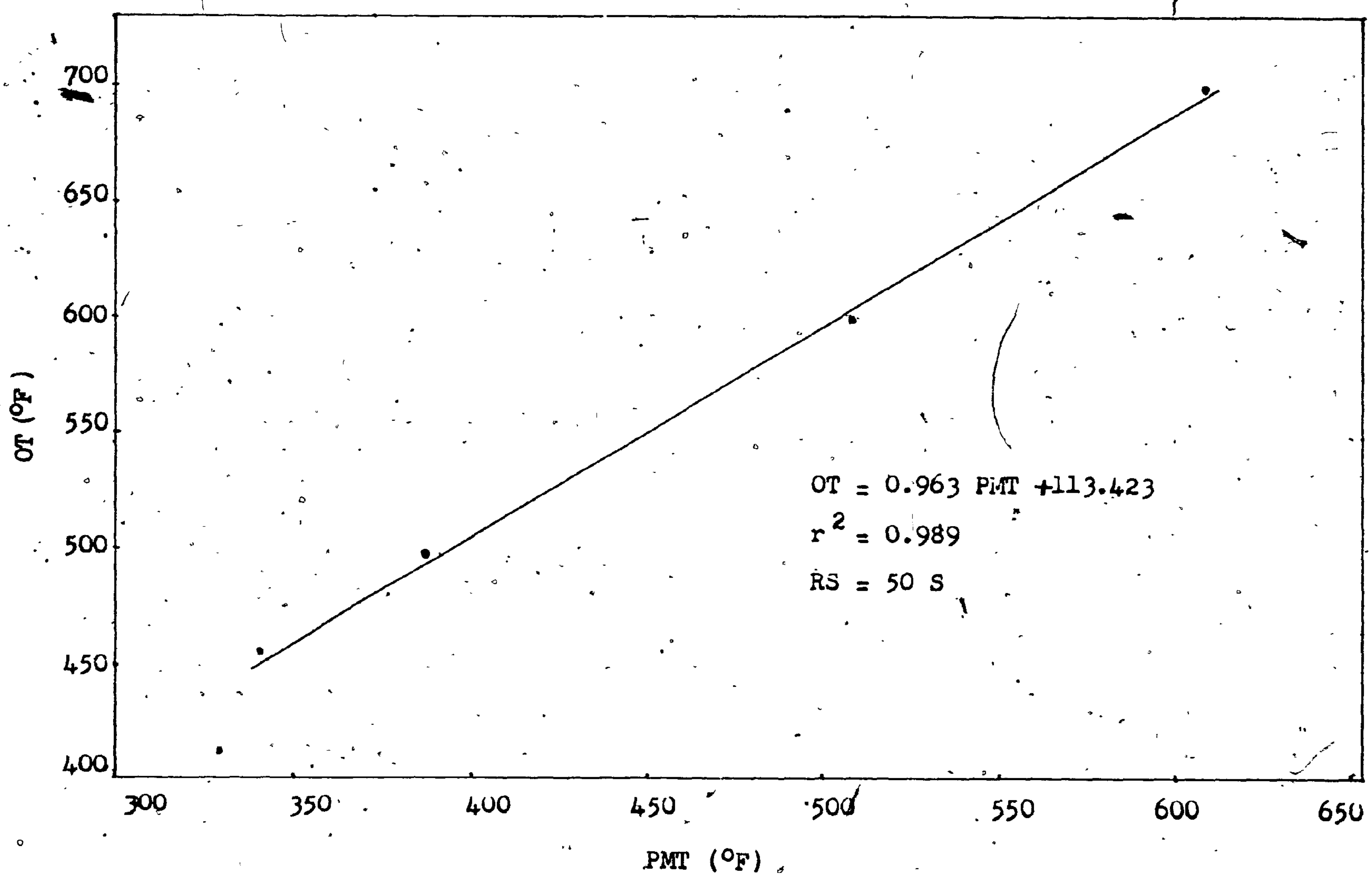
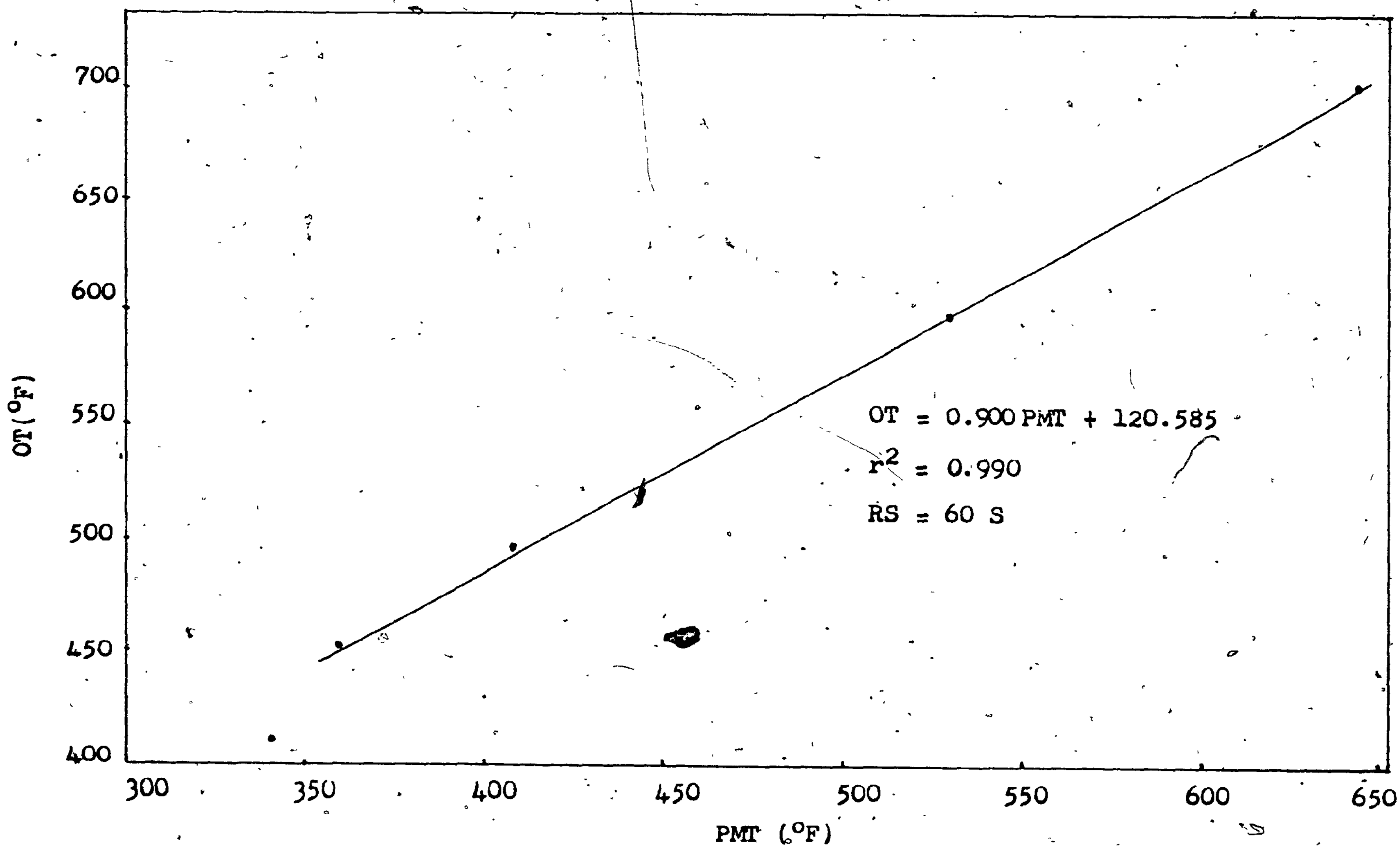


FIGURE 3.2.11

OVEN TEMPERATURE (OT) VS PEAK METAL TEMPERATURE (PMT)



It is interesting to note that the intercepts and regression coefficients of Equations 3.2.6 to 3.2.10 are related by a logarithmic curve (see Figure 3.2.12 and 3.2.13) to residence time. The corresponding equations were calculated by using linear regression, and data was obtained from Table 3.2.5, and they are shown below (see Figures 3.2.14 and 3.2.15).

$$m = -89.678 + 51.774 \ln RS \qquad 3.2.11$$

$$f = 2.795 - 0.467 \ln RS \qquad 3.2.12$$

where

m = intercept

f = regression coefficient

and the estimator factors are shown on Table 3.2.7. The corresponding estimated values are shown on Table 3.2.8.

FIGURE 3.2.12
INTERCEPT (m) VS RESIDENCE TIME (RS)

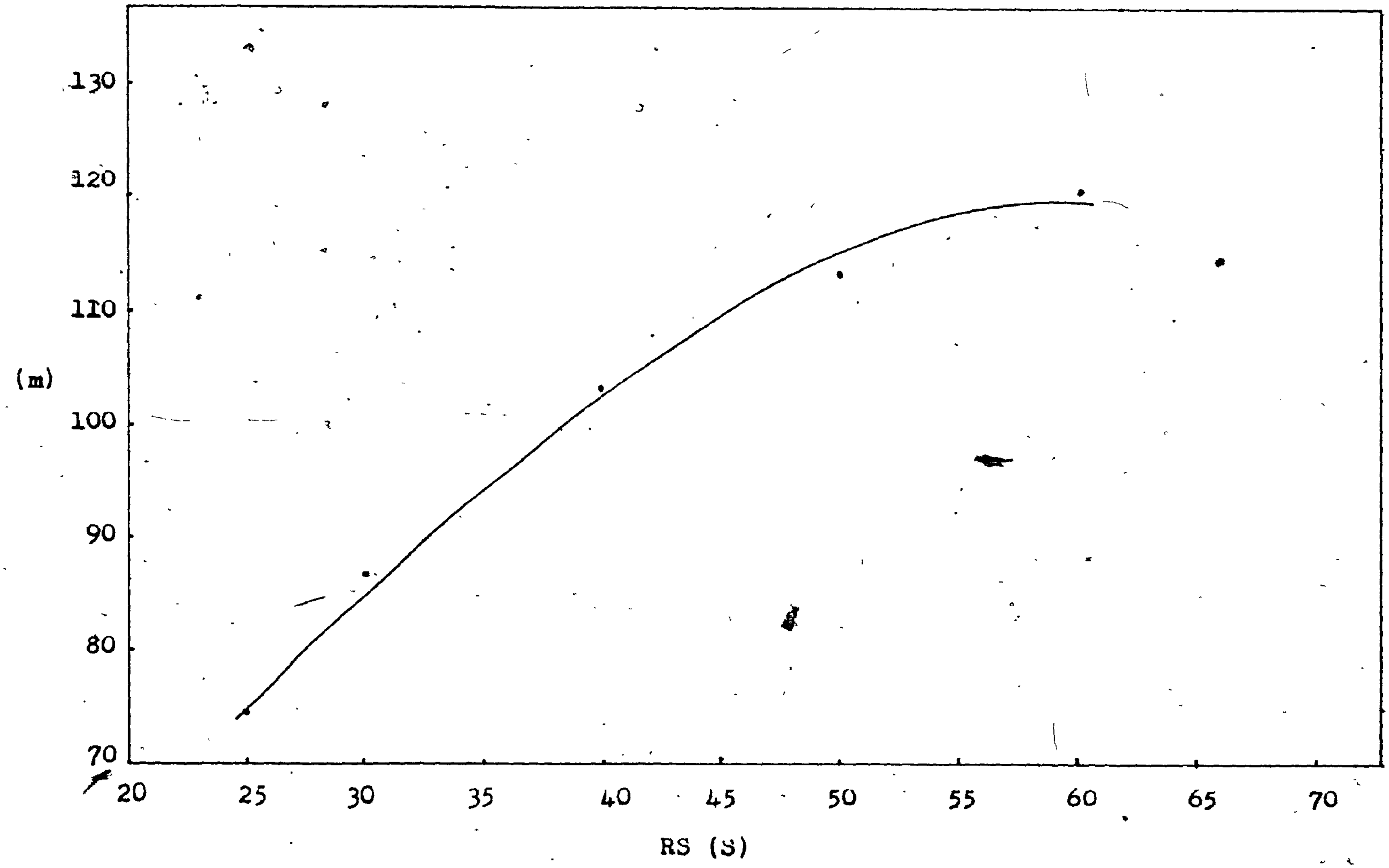


FIGURE 3.2.13
REGRESSION COEFFICIENT (f) VS RESIDENCE TIME (RS)

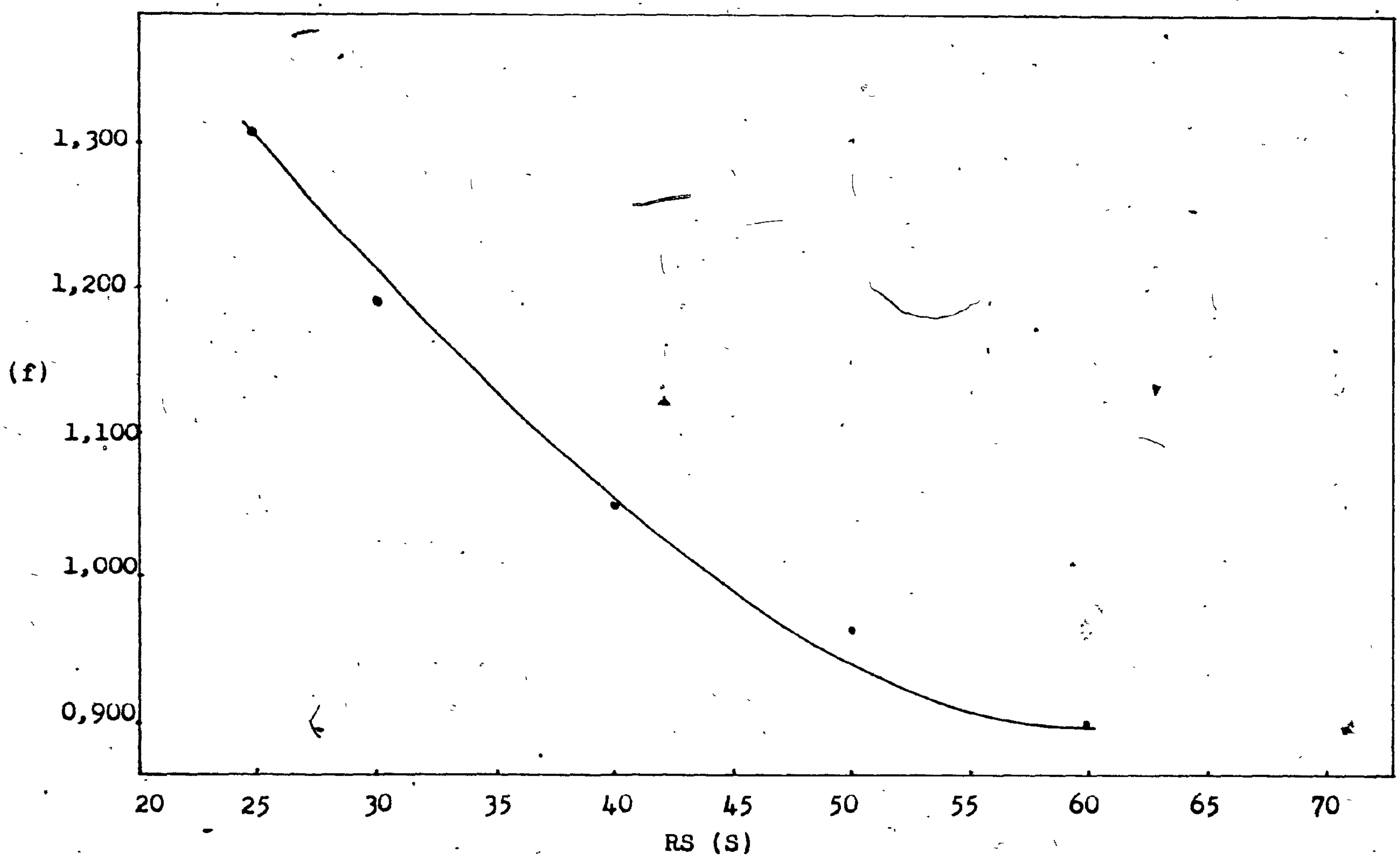


TABLE 3.2.7

ESTIMATOR FACTORS

	Intercept	Regression coefficient (slope)	Coefficient of determination
For m	-89.678	51.774	0.992
For f	2.795	-0.467	0.990

TABLE 3.2.8

ESTIMATED INTERCEPTS (m) AND REGRESSION COEFFICIENTS (f), USING EQUATIONS 3.2.11 AND 3.2.12

Residence time (s)	m	f
25	76.976	1.292
30	86.416	1.207
40	101.310	1.072
50	112.863	0.968
60	122.303	0.883

FIGURE 3.2.14

INTERCEPT (m) VS NATURAL LOGARITHM OF RESIDENCE TIME (ln RS)

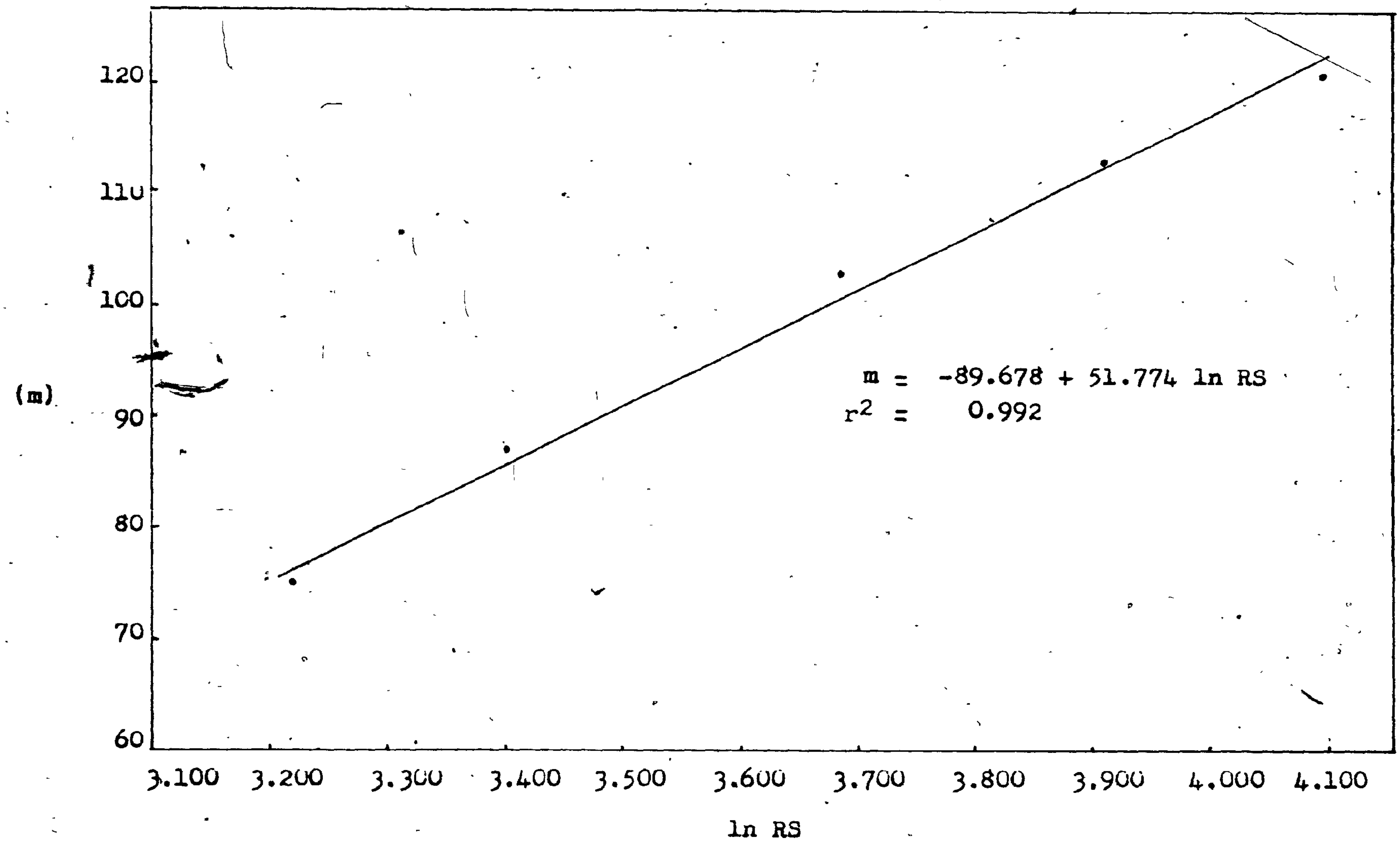
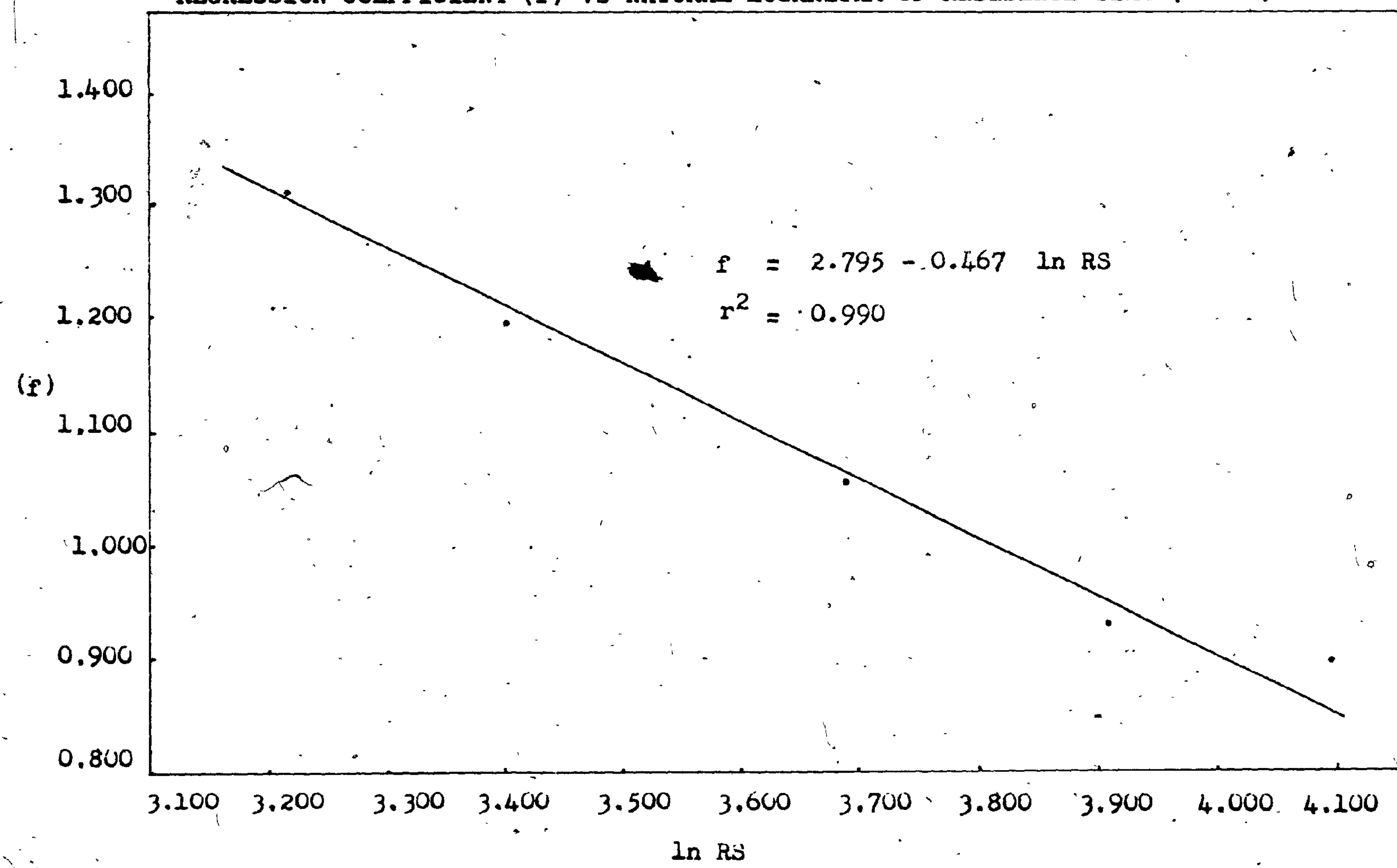


FIGURE 3.2.15

REGRESSION COEFFICIENT (f) VS NATURAL LOGARITHM OF RESIDENCE TIME (ln RS)



Equations 3.2.11 and 3.2.12 allow the construction of equations relating oven temperature (OT) and peak metal temperature (PMT) at any given residence time (RS). For example for a 50 sec. residence time the equation would be:

$$OT = 0.968 \, PMT + 112.863 \qquad 3.2.13$$

which is very close to equation 3.2.9

The utility of equations 3.2.11 and 3.2.12 lies in the fact that, without doing any experimental measurements,it is possible to determine the oven temperature (OT) for a desired peak metal temperature at a given residence time (RS). (e.g., for 50 sec. of RS and 400 ^{o}F of PMT, the oven temperature will be: $OT \simeq 500$ which agrees very well with the experimental values).

Figure 3.2.16 has a plot between the oven temperature (OT) and the residence time (RS), at a given peak metal temperature (PMT).(Data on Table 3.2.9). Figure 3.2.17 represents the plots of oven temperature (OT) vs a power of residence time (RS^e), for a given peak metal temperature. (Data on Table 3.2.12). As one can see that these curves are of the type:

$$Y = p. \, x^e \qquad 3.2.14$$

or

$$OT = p. \, RS^e \qquad 3.2.15$$

and these were calculated by using linear regression. Their data are presented on Table 3.2.9. Theestimator factor and estimated values are shown in Table 3.2.10 and 3.2.11 respectively.

And the equations are:

FOR	300°F	OT	=	$1656.028\ RS^{-0.387}$		3.2.16
FOR	320°F	OT	=	$1575.641\ RS^{-0.349}$		3.2.17
FOR	340°F	OT	=	$1510.134\ RS^{-0.317}$		3.2.18
FOR	360°F	OT	=	$1455.871\ RS^{-0.291}$		3.2.19
FOR	380°F	OT	=	$1410.595\ RS^{-0.268}$		3.2.20
FOR	400°F	OT	=	$1372.579\ RS^{-0.249}$		2.2.21
FOR	420°F	OT	=	$1340.228\ RS^{-0.232}$		3.2.22

TABLE 3.2.9

ESTIMATED RESIDENCE TIME (RS)

USING EQUATIONS 3.2.1 TO 3.2.5

PMT °F(°C)	300	320	340	360	380	400	420
OT °F(°C)	RS(S)	RS(S)	RS(S)	RS(S)	RS(S)	RS(S)	RS(S)
412 (211)	33.99	44.16	57.38	74.55	96.86	125.85	163.52
455 (235)	32.00	39.42	48.55	59.79	73.64	90.71	111.72
499 (259)	20.97	25.50	31.00	37.69	45.82	55.70	67.71
600 (316)	13.48	15.29	17.34	19.66	22.29	25.28	28.67
700 (371)	9.62	10.70	11.90	13.23	14.71	16.36	18.20

TABLE 3.2.10

ESTIMATOR FACTORS OF EQUATIONS

3.2.16 TO 3.2.22

PMT °F(°C)	Exponential (e)	Regression Coefficient (p)	Coefficient of Determination (r^2)
300	-0.387	1656.028	0.979
320	-0.349	1575.641	0.985
340	-0.317	1510.134	0.988
360	-0.291	1455.871	0.990
380	-0.268	1410.595	0.991
400	-0.249	1372.579	0.992
420	-0.232	1340.228	0.992

TABLE 3.2.11

ESTIMATED RESIDENCE TIME

(RS) USING EQUATIONS 3.2.16 TO 3.2.22

PMT OT	°F(°C) °F(°C)	300 RS(S)	320 RS(S)	340 RS(S)	360 RS(S)	380 RS(S)	400 RS(S)	420 RS(S)
412	(211)	36.41	46.69	60.19	76.55	98.72	125.59	161.48
455	(235)	28.17	35.13	44.55	54.42	68.16	84.30	105.26
499	(259)	22.19	26.97	32.89	39.63	48.30	58.18	70.71
600	(316)	13.78	15.90	18.39	21.03	24.28	27.75	31.95
700	(371)	9.25	10.22	11.31	12.38	13.66	14.94	16.44

TABLE 3.2.12

DATA OBTAINED FROM EQUATIONS 3.2.16 TO 3.2.22

PMT $^oF(^oC)$	300	320	340	360	380	400	420
OT $^oF(^oC)$	$RS^{-0.387}$	$RS^{-0.349}$	$RS^{-0.317}$	$RS^{-0.291}$	$RS^{-0.268}$	$RS^{-0.249}$	$RS^{-0.232}$
412 (211)	0.255	0.267	0.277	0.285	0.294	0.300	0.307
455 (235)	0.262	0.277	0.292	0.304	0.316	0.325	0.335
499 (259)	0.308	0.323	0.337	0.348	0.359	0.368	0.376
600 (316)	0.365	0.386	0.405	0.420	0.435	0.447	0.459
700 (371)	0.416	0.437	0.456	0.472	0.486	0.499	0.510

FIGURE 3.2.16

OVEN TEMPERATURE (OT) VS RESIDENCE TIME (RS)

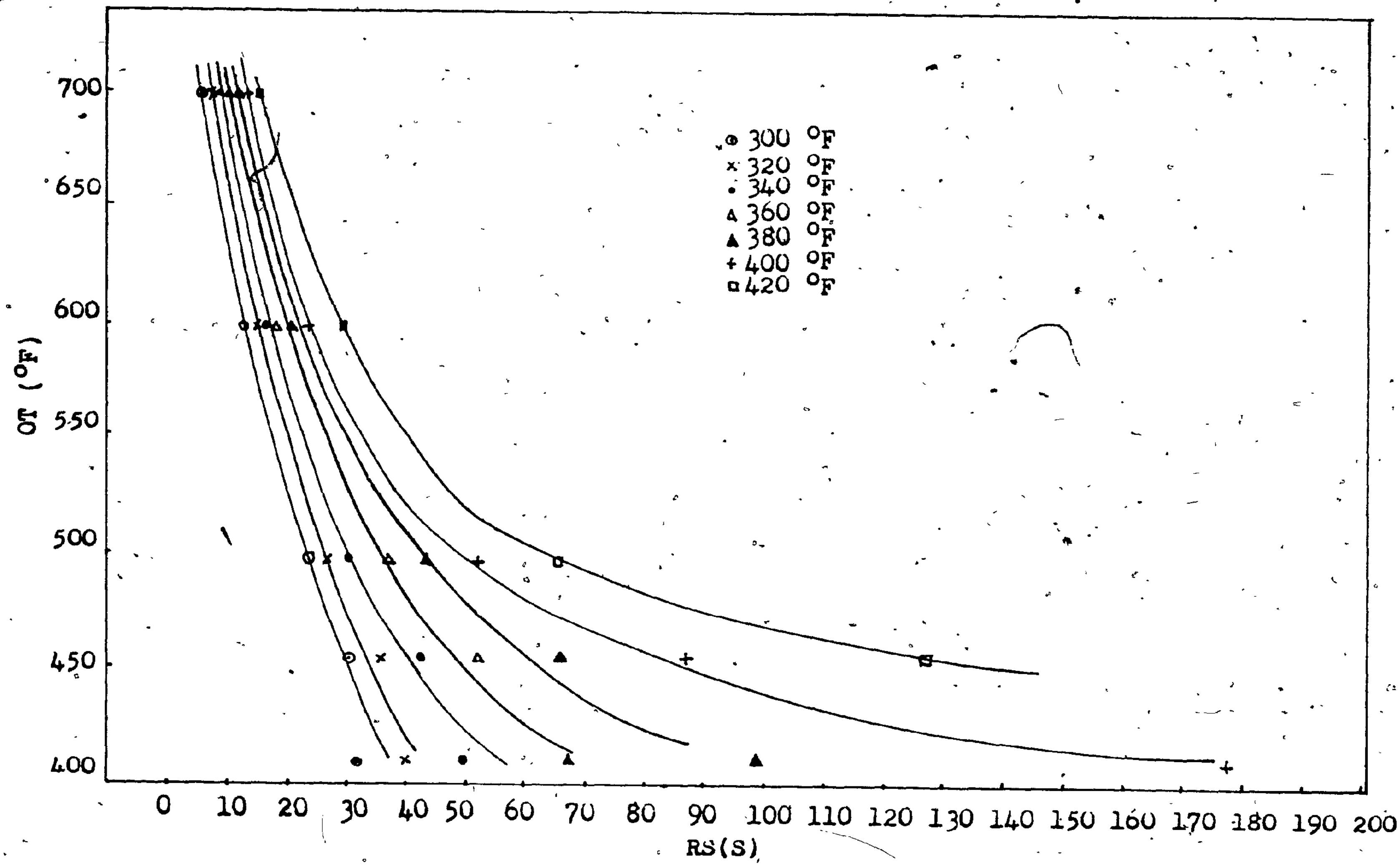
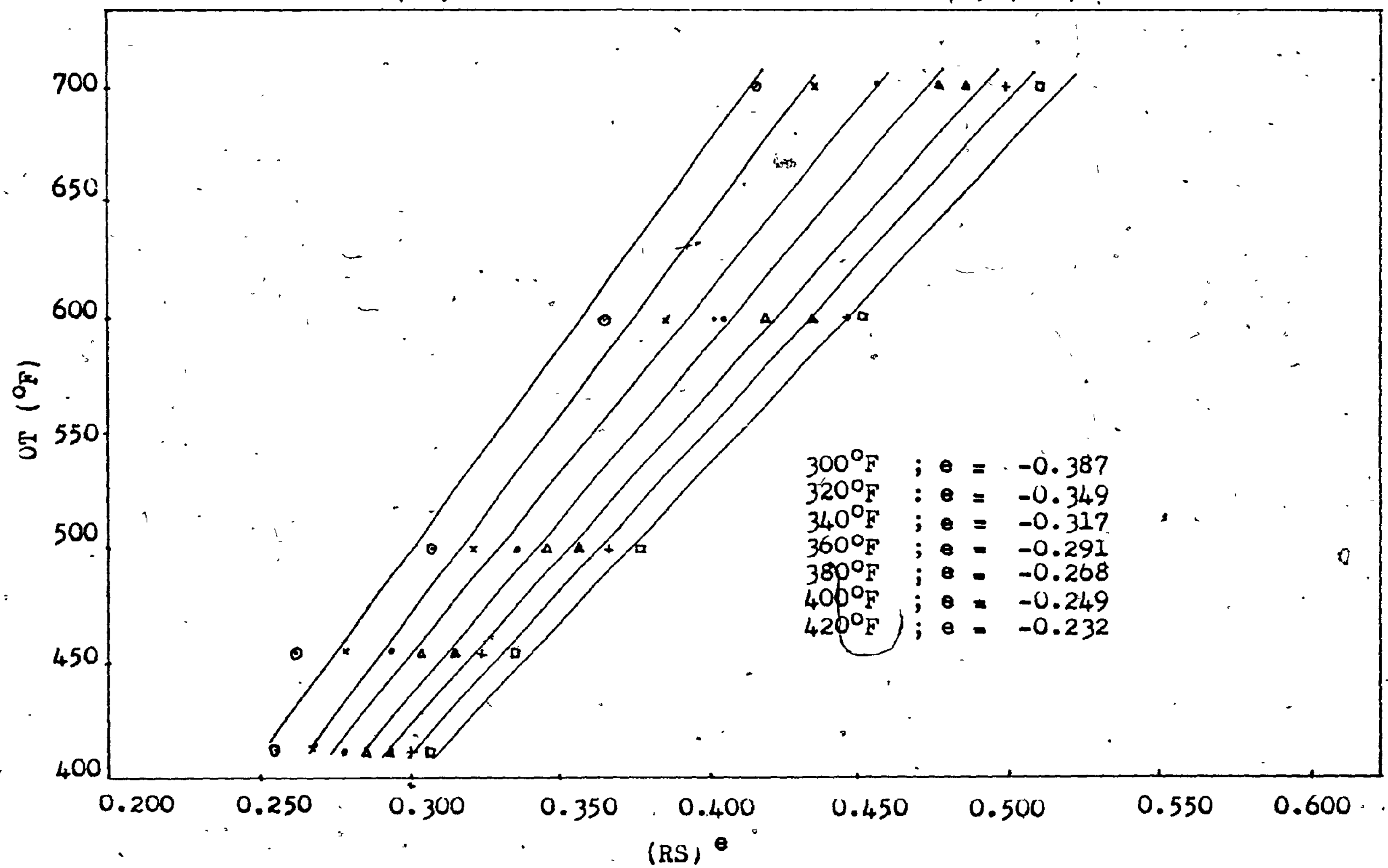


FIGURE 3.2.17

OVEN TEMPERATURE (OT) VS RESIDENCE TIME TO THE POWER (e) (RS^e)



One can note that the regression coefficient and the exponential factors of equations 3.2.16 to 3.2.22 are related by a logarithmic curve to peak metal temperature (PMT).(Figure 3.2.18 and 3.2.19 and data on Table 3.2.10). Their equations were calculated using the linear regression method, data on Table 3.2.10. See Figures 3.2.20 and 3.2.21.

The equations are:

$$e = -2.991 + 0.458 \ln PMT \qquad 3.2.23$$

$$p = 6955.962 - 932.253 \ln PMT \qquad 3.2.24$$

where e = exponential factors

p = Regression coefficients.

The corresponding estimator factors and estimated values are shown on Table 3.2.13 and 3.2.14 respectively.

Equations 3.2.23 and 3.2.24 are useful because they allow the construction of equation relating oven temperature (OT) and residence time (RS) at any given peak metal temperature PMT). For example, for a $400^{o}F$ of PMT the equation would be:

$$OT = 1370.401 \, RS^{-0.247} \qquad 3.2.25$$

which is similar to equation 3.2.21. Thus the predicted oven temperature at 50 s of residence time would be:

$OT \doteq 521^{o}F$, which is close to the experimental value.

FIGURE 3.2.18

EXPONENTIAL (e) VS PEAK METAL TEMPERATURE (PMT)

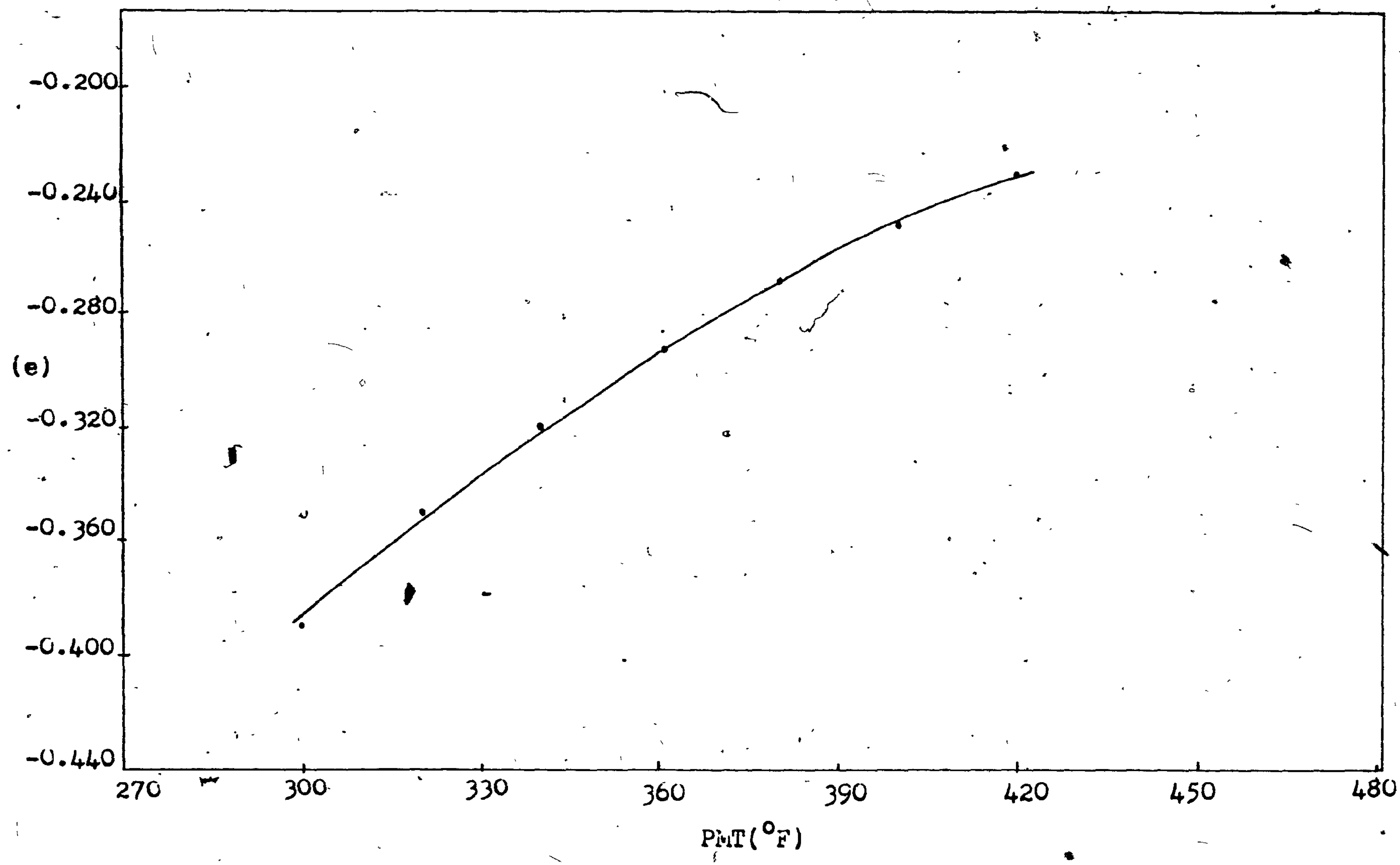


FIGURE 3.2.19

REGRESSION COEFFICIENT (p) VS PEAK METAL TEMPERATURE (PMT).

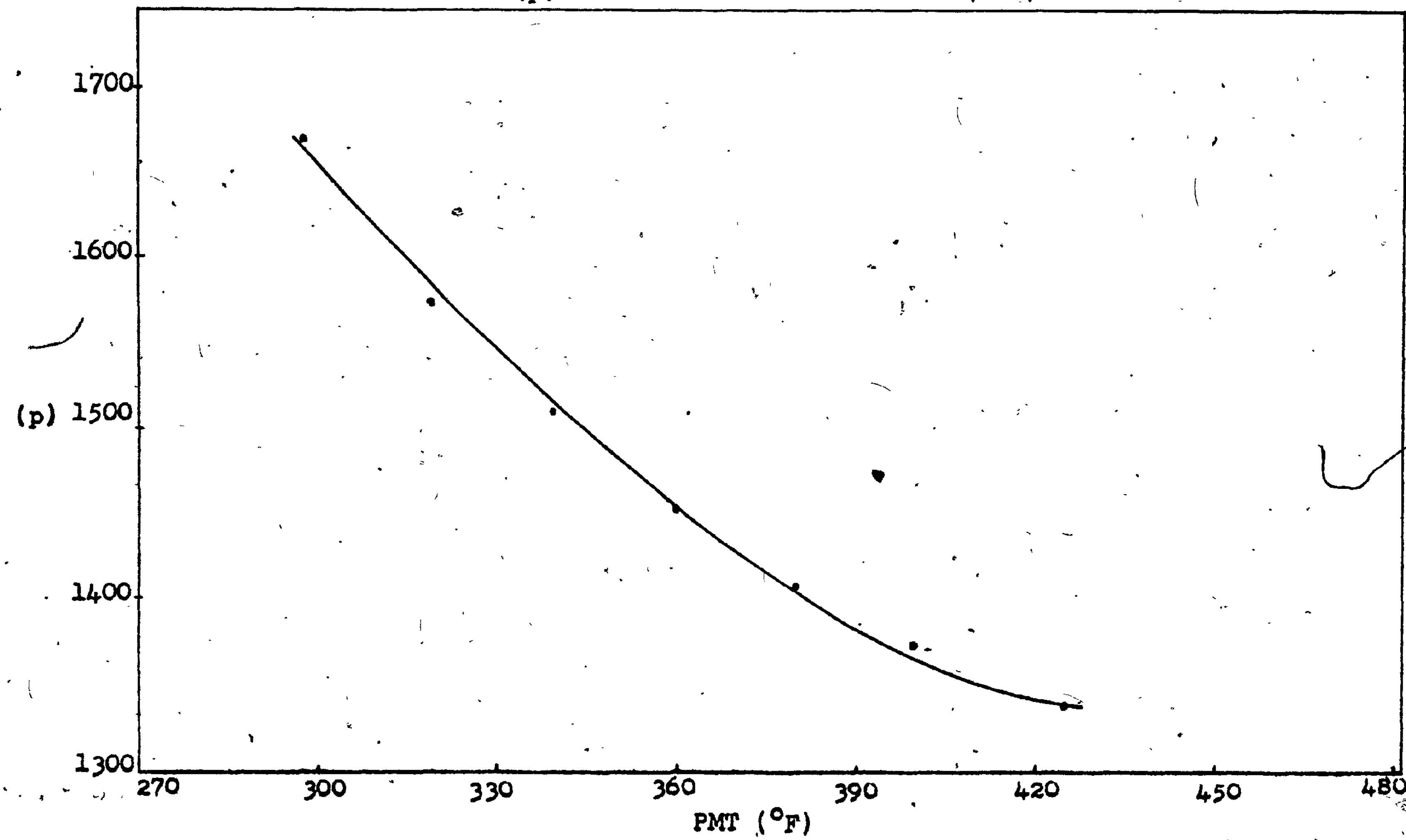


TABLE 3.2.13

ESTIMATOR FACTORS OF EQUATIONS

3.2.23 AND 3.2.24

	Intercept	Regression coefficient (slope)	Coefficient of determination
For e	-2.991	+0.458	0.991
For p	6955.962	932.253	0.988

TABLE 3.2.14

ESTIMATED EXPONENTIAL (e) AND

REGRESSION COEFFICIENT (p)

USING EQUATIONS 3.2.23 AND 3.2.24

PMT $^{o}F(^{o}C)$	Exponential (e)	Regression Coefficient (p)
300	-0.379	1638.594
320	-0.349	1578.427
340	-0.321	1521.910
360	-0.295	1468.624
380	-0.270	1418.220
400	-0.247	1370.401
420	-0.275	1324.916

FIGURE 3.2.20

EXPONENTIAL (e) VS THE NATURAL LOGARITHM OF PEAK METAL TEMPERATURE (PMT)

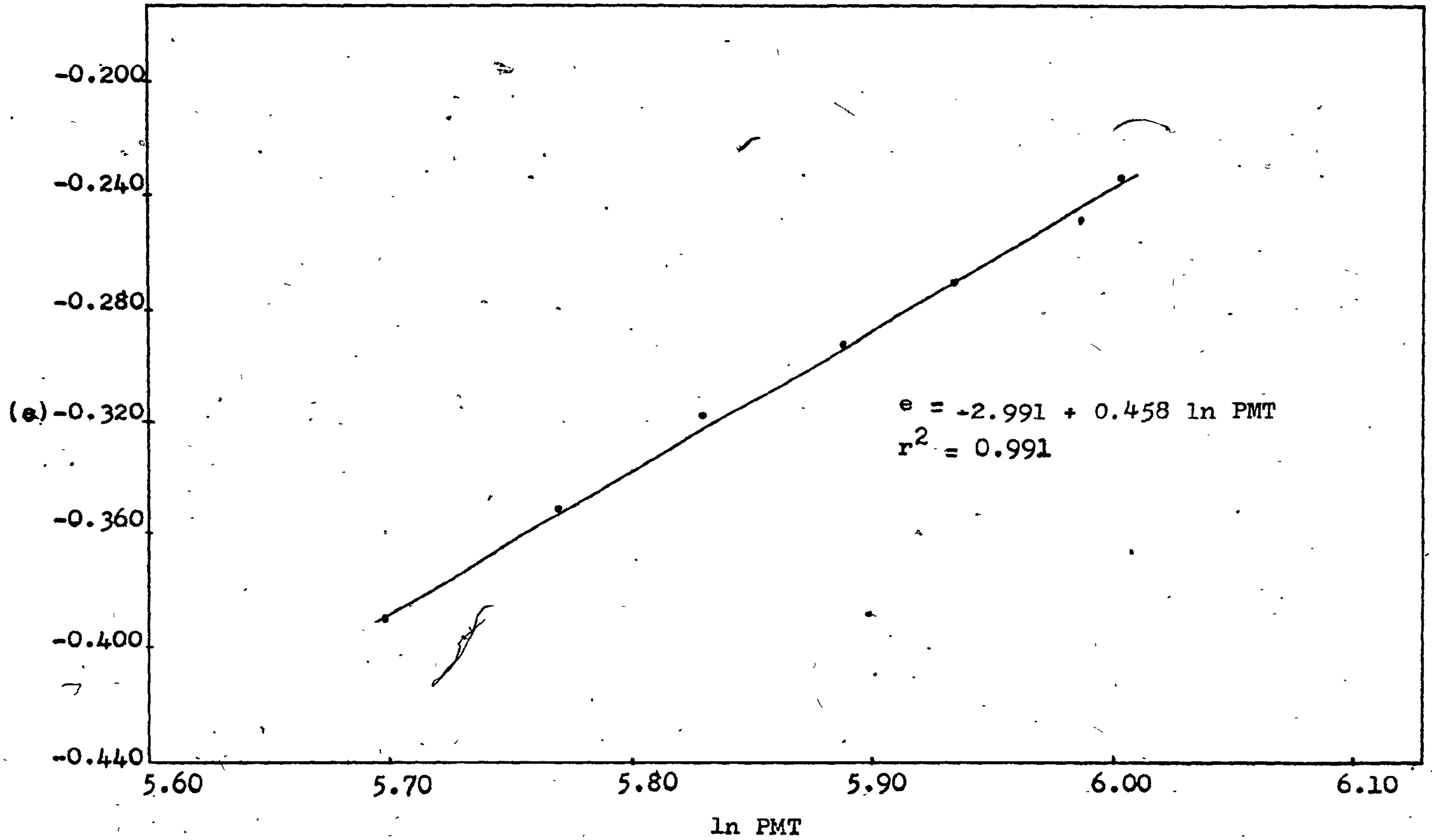
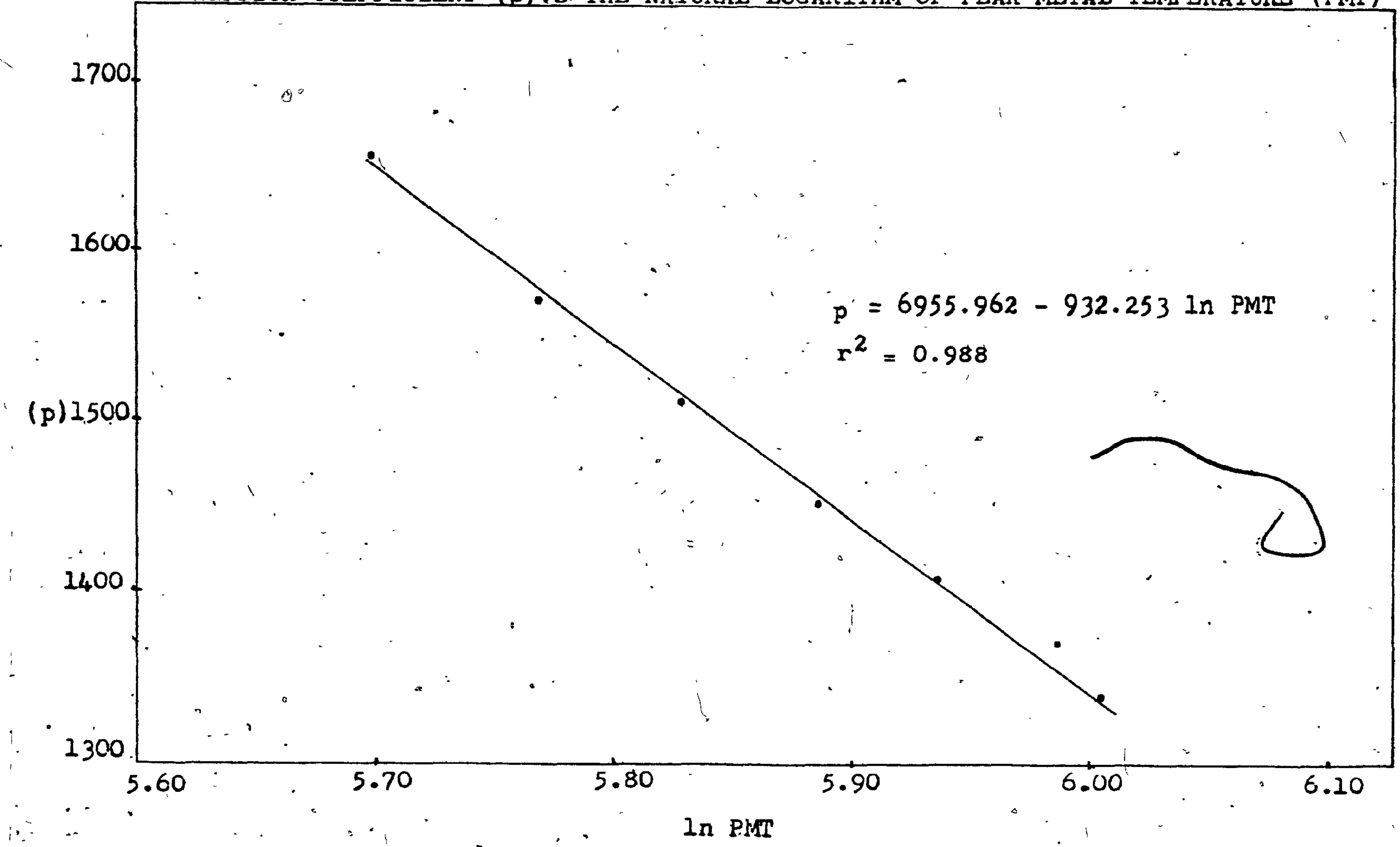


FIGURE 3.2.21

REGRESSION COEFFICIENT (p) VS THE NATURAL LOGARITHM OF PEAK METAL TEMPERATURE (PMT)



The last step in the statistical analysis was to combine the three variables, i.e. peak metal temperature (PMT), resisence time (RS) and oven temperature (OT) into one equation. This was done using the multiple regression programme belonging to the Music Statpak file, available on the IBM computer at McGill University.

The technique used was essentially trial and error. All the data, once incorporated onto a suitable file, was modified in numerous different ways, and each modification was used to generate an equation incorporating the three variables. For each modification, the coefficient of correlation was noted, and the equation finally chosen, as best describing the relationship between the three variables, was the one for which the coefficient of correlation was closest to 1.

The data used are shown in Table 3.2.15. The equation chosen, as best representing the data was as follows:-

$$PMT = -675.619 - 2370.677\frac{1}{RS} + 54.045 \ln RS + 40.679\sqrt{OT} \qquad 3.2.26$$

and this equation had a coefficient of correlation of 0.97

Using equation 3.2.26, and the data for OT, and for RS, as tabulated in Table 3.2.15, corresponding values of PMT were estimated; and these values are also tabulated in Table 3.2.15 for comparison.

TABLE 3.2.15

DATA AND ESTIMATED VALUES

OT(^oF)	RS(s)	PMT(^oF)	Estimated PMT(^oF)
700	12	340	337.40
700	17	410	414.33
700	28	500	496.08
600	15	310	309.13
600	17	340	334.49
600	20	360	364.19
600	24	390	393.80
600	25	405	399.96
600	27	420	411.14
600	40	465	460.92
499	30	317	337.89
499	40	370	373.19
499	50	401	397.10
501	70	441	430.65
500	90	454	450.85
499	130	468	477.92
455	30	290	296.90
455	50	338	356.12
453	60	370	371.96
455	70	375	387.85
455	100	420	417.28
453	130	423	435.03
411	50	326	313.09
414	60	347	333.85
413	70	355	346.83
413	100	385	376.27
413	130	400	395.92

3.3 Effect of Primer Baking Temperature

Tables Nos. 4.4.1 to 4.4.10 show the effect on the behavior of the top coat applied after curing of the primer at different temperatures relative to the soak test.

Tables 4.4.1 to 4.4.6 summarize the results where the top coat and the primer were applied with strokes at right angles to each other. Tables 4.4.7 to 4.4.10 summarize the results where the top coat and the primer were applied in the normal fashion, (e.g. with strokes in the same direction).

3.4 CONCLUSIONS

The first conclusion that one can be derived from the data compiled in Tables 4.4.1 to 4.4.10 is that, unless the primer coat achieves a peak metal temperature of at least 370°F which can be achieved by having been in an oven at 500°F for about 40 sec some of the plates will fail upon top coat application (see Tables 4.4.2 & 4.4.8). On the other hand, when the primer coat does achieve this peak metal temperature, no failure occurs after top coat application, even at a peak metal temperatures as low as 300°F (30 sec); residence time, Tables 4.4.4 & 4.4.10). Thus proper curing of the primer coat is of utmost importance in order to achieve a good adhesion between the film and the metal.

Typically, the average temperature for a primer oven (as used at the Hunter Douglas Company) is about 510°F. But the assembly lines move at either 300 ft/min (a residence time of 26 sec.) or 400 ft/min (i.e. 19.5 sec); and considering the temperature of the primer oven, these residence times will yield a calculated P.M.T. (using equations 3.2.11 and 3.2.12) of 337°F and 307°F respectively. There is thus not enough time for the metal to reach the minimum PMT of 370°F, which this work has shown to be necessary for good adherence between the paint film and the metal.

Figures 3.4.2 and 3.4.3 represent the zone of no-failure for primer as well as the top coat. It has been obtained by plotting points of failure, thereby obtaining curves intersecting the curves relating other variables such as PMT, OT, HS, etc.

The equations representing the failure curves are shown below and they were calculated by using linear regression. The data for these figures is in Table 3.4.1.

$PMT = 559.972 - 52.911 \ln RS$ 3.4.1 Fig. 3.4.4

$OT = 30.581\, e^{0.0076\, PMT}$ 3.4.2 Fig. 3.4.5

The estimator factors are presented on Table 3.4.2.

TABLE 3.4.1

DATA FOR FAILURE POINTS

OT (^{o}F)	PMT (^{o}F)	RS (s)	$e^{0.0076\ PMT}$
700	410	17	22.56
600	390	24	19.38
500	370	40	16.64
455	351	50	14.41
412	342	60	13.45

TABLE 3.4.2

ESTIMATED FACTORS

Equation number	Intercept	Regression coefficient	Coefficient of correlation
3.4.1	559.972	-52.911	0.988
3.4.2	0.0076	30.581	0.993

FIGURE 3.4.1

TEMPERATURE PROFILE FOR A TOP COAT OVEN.

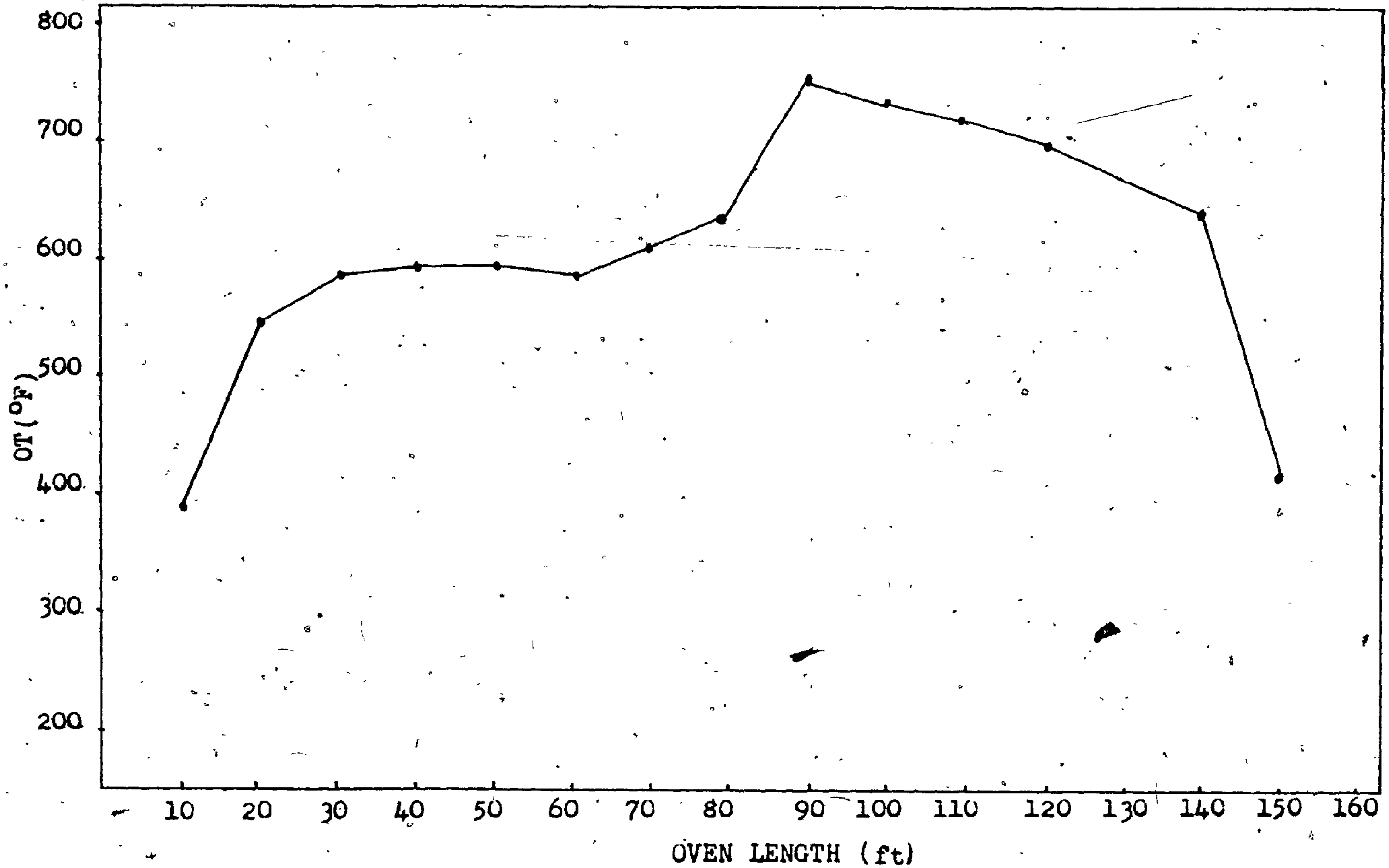


FIGURE 3.4.2

FAILURE POINTS ON A PEAK METAL TEMPERATURE (PMT)VS RESIDENCE TIME (RS) PLOT

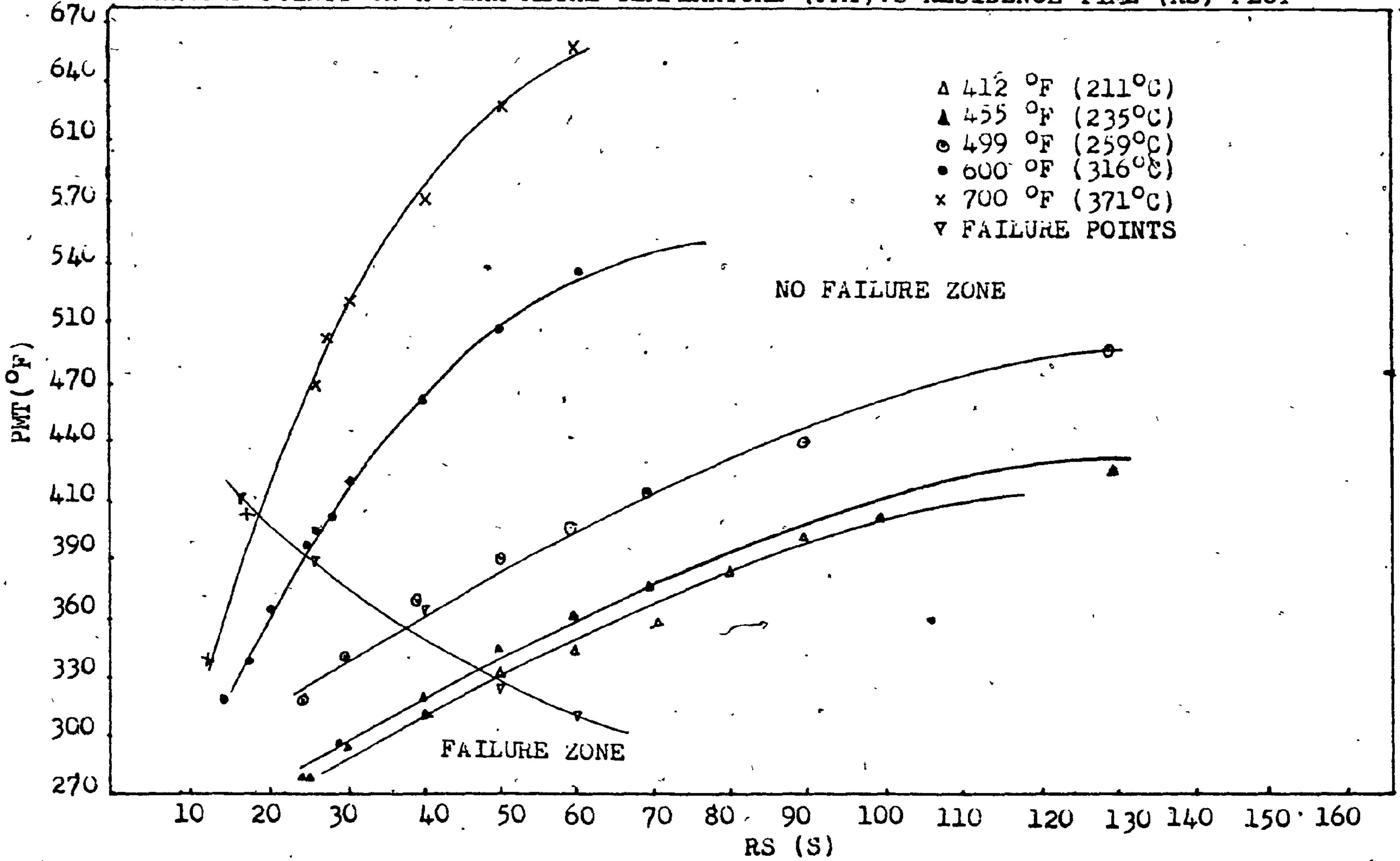


FIGURE 3.4.3

FAILURE POINTS ON AN OVEN TEMPERATURE (OT) VS PEAK METAL TEMPERATURE (PMT) PLOT

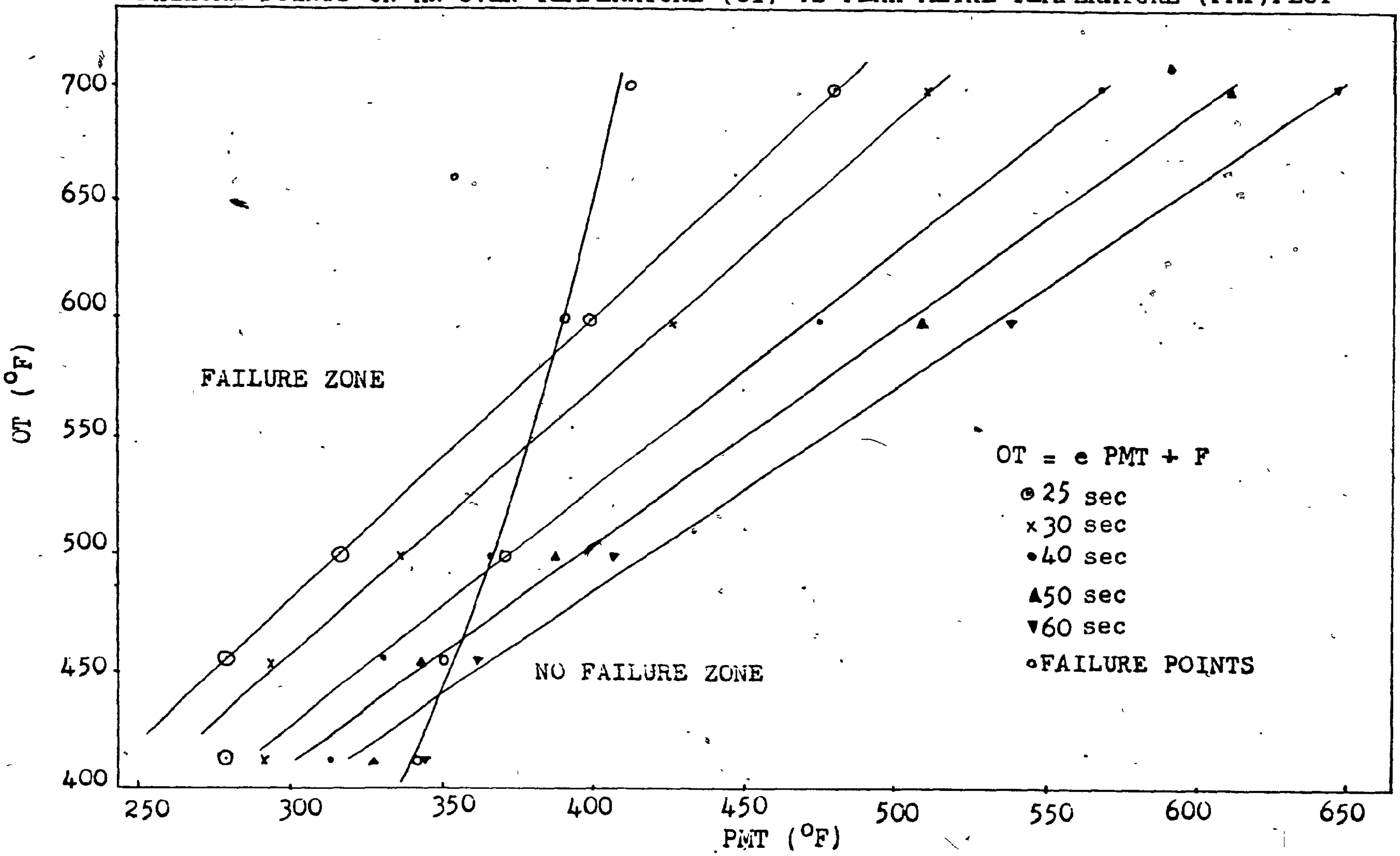


FIGURE 3.4.4

PEAK METAL TEMPERATURE (PMT) VS NATURAL LOGARITHM OF RESIDENCE TIME (ln RS)

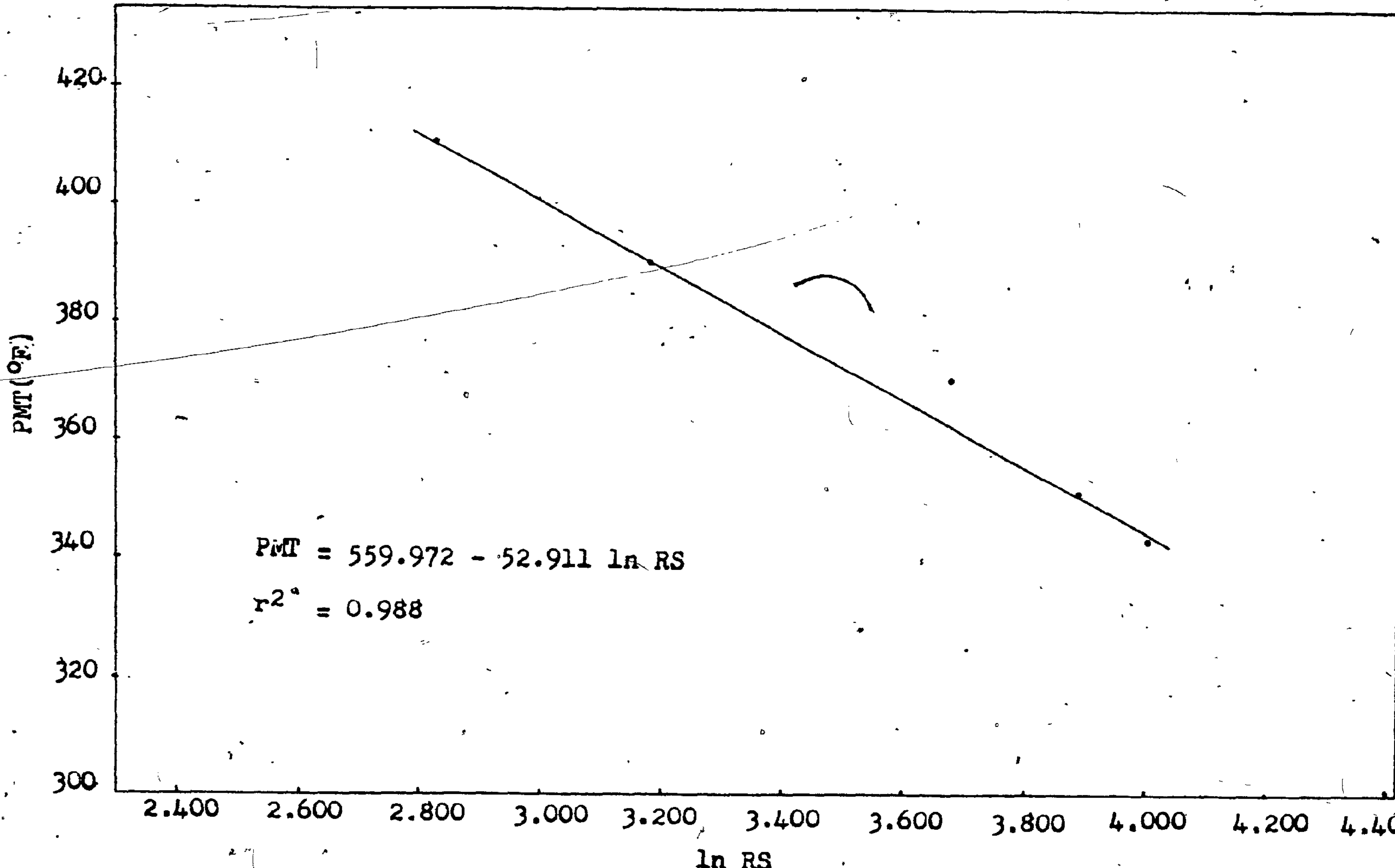
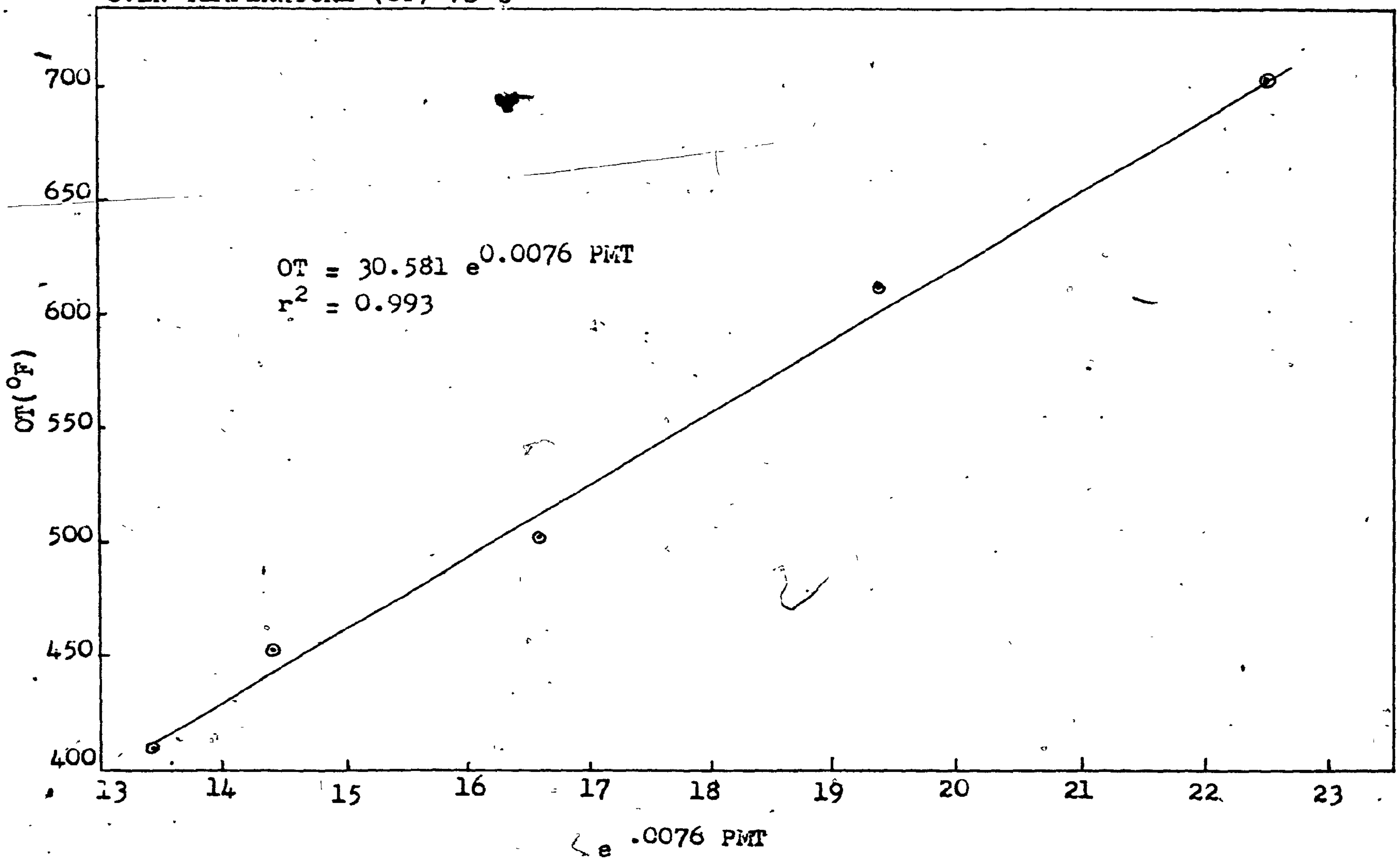


FIGURE 3.4.5

OVEN TEMPERATURE (OT) VS $e^{0.0076\ PMT}$



On Figure 3.4.1, we have a profile temperature for a top coat oven used at Hunter Douglas Co. of Canada. The residence time, corresponding to the two metal strip velocities are: 22.5 s and 30 s respectively. The average oven temperature is about 610 °F. The corresponding Peak metal temperature values (obtained by using Equations 3.2.11 and 3.2.12 are 402 °F and 434 °F respectively). It is clear from Figures 3.4.2 and 3.4.3, that the value of 402 °F falls very close to the failure zone. Hence, in the case of plates pretreated with Bonderite 1415, it does not appear wise to use an assembly line working at 400 ft/minute (residence time = 22.5s), for the given conditions of oven temperature and oven length.

On the other hand, the value of 434 °F lies well in the no-failure zone. Therefore, with an assembly line working at 300 ft./minute, (residence time = 30 sec), and at the given conditions of oven length and temperature, a plate pretreated with Bonderite 1415 should not fail upon water soaking, even if the primer temperature values do not reach the minimum peak metal temperature.

3.5 Effect of Chemicals

A series of tests were conducted in order to determine the ability of the film to withstand various chemical treatments.

From here on, the metal plates were primed and used at conditions that should be expected to produce film failure upon water soaking (at specific residence time (RS) values). These primed plates were then top coated and cured at different peak metal temperatures (PMT) and then soaked in solutions of different pH values.

The pH was measured using a Methron / 300 B. pH meter.

All the results are given in Tables 4.5.1 to 4.5.35.

From Tables 4.5.1 to 4.5.10 we have for the acidic series, Bonderite 1415 as the pretreatment, and from Tables 4.5.11 to 4.5.20 we have Bonderite 1414 as the pretreatment.

The basic series is presented from Tables 4.5.21 to 4.5.27 for Bonderite 1415 as the pretreatment and from Tables 4.5.28 to 4.5.35 for Bonderite 1414 as the pretreatment.

As is apparent from Tables 4.5.2, 4.5.7, 4.4.12, 4.5.17 and 4.5.18, the film coating does not adhere at all in the presence of a strong acid solution. However, as the acidity of the solutions decrease (i.e. for increasing pH) the films on plates pretreated with Bonderite 1414 appear to adhere better than the films on plates pretreated with Bonderite 1415. This is true especially for plates soaked in sulfuric acid solutions, Tables 4.5.9, 4.5.10, 4.5.19 and 4.5.20.

Where a nitric acid solution of moderate acidity is used for the soak test, plates pretreated with Bonderite 1415 do not fail even at Peak metal temperature as low as 300 °F (RS = 30 sec for an oven temperature of 500 °F), (Tables 4.5.4 and 4.5.5). It seems as if there is an improvement towards film resistance, when top coated plates are soaked in nitric acid solutions in the pH range 3.00 to 4.00. But these plates do fail (in the usual manner) upon soaking in sulfuric acid solutions at the same pH range (Tables 4.5.9 and 4.5.10). The behaviour of plates pretreated with Bonderite 1414 is completely normal, (see Tables 4.5.19 and 4.5.20).

In the presence of alkaline solutions, plates pretreated with both Bonderite 1415 and Bonderite 1414 behave normally and no anomalous effects seem to be present (tables 4.5.22 to 4.5.35).

It is suggested that more work should be carried out in this area in order to have a better understanding of the action of various chemicals on the various films.

4. DATA PRESENTATION

The experimental data to be presented, consist of the following sections:-

4.1 Primed metal

4.2 Top coated metal

4.3 Experimental curves

4.4 Effect of primer baking temperature

4.5 Effect of Chemicals

The terms that appear on the Tables have been explained earlier on Section 3.1.

4.1 Primed Metal

TABLE 4.1.1

SURFACE: PRIMED METAL WITH

BONDERITE 1415 - PRETREATMENT

Average oven temperature: 502 °F (261 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	P.M.T. °F(°C)	Average (PMT) °F(°C)	R.S. (s)
1-1	24	total	504(262)	330(166)	320(160)	30
1-2	24	total	500(260)	310(154)		30
1-3	23	slightly	490(254)	370(188)	370(188)	40
1-4	23	slightly	491(255)	370(188)		40
1-5	24	none	500(260)	404(207)	402(206)	50
1-6	24	none	509(265)	400(204)		50
1-7	24	none	504(262)	425(218)	430(221)	70
1-8	24	none	506(263)	430(221)		70
1-9	24	none	509(265)	435(224)		70

TABLE 4.1.2

SURFACE: PRIMED METAL WITH

BONDERITE 1415 - PRETREATMENT

Average oven temperature: 453 °F (234 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	P.M.T. °F(°C)	Average (PMT) °F(°C)	R.S. (s)
1-10	24	total	457(236)	350(177)	351(177)	50
1-11	24	slightly	453(234)	352(178)		50
1-12	24	none	450(232)	370(188)	370(188)	60
1-13	24	none	446(230)	370(188)		60
1-14	24	none	455(235)	380(193)	375(191)	70
1-15	24	none	455(235)	370(188)		70
1-16	24	none	459(237)	420(216)	420(216)	100
1-17	24	none	457(236)	420(216)		100

TABLE 4.1.3

SURFACE: PRIMED METAL WITH

BONDERITE 1415 - PRETREATMENT

Average oven temperature: 414 °F (212°C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	P.M.T. °F(°C)	Average (PMT) °F(°C)	R.S. (s)
1-18	22	total	406(208)	290(143)	290(143)	40
1-19	22	total	410(210)	290(143)		40
1-20	22	total	412(211)	350(177)	330(166)	50
1-21	22	total	401(205)	310(154)		50
1-22	22	total	406(208)	330(166)		
1-23	22	slightly	408(209)	345(174)	340(171)	60
1-24	22	slightly	408(209)	330(149)		60
1-25	22	slightly	410(210)	345(174)		60
1-26	22	none	415(213)	365(185)	360(182)	70
1-27	22	none	415(213)	355(179)		70
1-28	22	none	415(213)	365(185)		70
1-29	22	none	415(213)	355(179)		70
1-30	22	none	417(214)	375(191)	380(193)	100
1-31	22	none	417(214)	385(196)		100
1-32	22	none	417(214)	380(193)		100
1-33	22	none	417(214)	380(193)		100
1-34	22	none	421(216)	400(204)	400(204)	130
1-35	22	none	421(216)	400(204)		130

TABLE 4.1.4

SURFACE: PRIMED METAL WITH

BONDERITE 1414 - PRETREATMENT

Average oven temperature: 499 ^{o}F (259 ^{o}C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. ^{o}F(^{o}C)	P.M.T. ^{o}F(^{o}C)	Average (PMT) ^{o}F(^{o}C)	R.St (s)
1-36	24	none	496(258)	320(160)	320(160)	30
1-37	24	none	493(256)	320(160)		30
1-38	24	none	500(260)	390(199)	395(202)	50
1-39	24	none	496(258)	400(204)		50
1-40	24	none	505(263)	450(232)	443(228)	70
1-41	24	none	502(261)	435(223)		70

TABLE 4.1.5

SURFACE: PRIMED METAL WITH

BONDERITE 1414 - PRETREATMENT

Average oven temperature: 460 °F (238 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	P.M.T. °F(°C)	Average (PMT) °F(°C)	R.S. (s)
1-42	24	none	460(238)	340(171)		50
1-43	24	none	459(237)	310(154)	322(161)	50
1-44	24	none	459(237)	315(157)		50
1-45	24	none	460(238)	375(191)	375(191)	70
1-46	24	none	459(237)	375(191)		70
1-47	24	none	460(238)	420(216)		100

TABLE 4.1.6

SURFACE: PRIMED METAL WITH

BONDERITE 1414 PRETREATMENT

Average oven temperature: 410 °F (210 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	P.M.T. °F(°C)	Average (PMT) °F(°C)	R.S. (s)
1-48	23	soft to fingernail	408(209)	310(154)	305(152)	50
1-49	23	soft to fingernail	408(209)	300(149)		50
1-50	23	none	410(210)	355(179)	358(181)	70
1-51	23	none	410(210)	365(185)		70
1-52	23	none	412(211)	390(199)	385(196)	100
1-53	23	none	410(210)	380(193)		100

4.2 Top Coated Metal

TABLE 4.2.1

SURFACE: PRIMED AND TOP COATED METAL

WITH BONDERITE 1415 PRETREATMENT

Average oven temperature: 500 °F (260 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	P.M.T. °F(°C)	Average (PMT) °F(°C)	R.S. (s)
2-1	19	total	502(261)	330(166)	320(160)	30
2-2	19	total	498(259)	310(154)		30
2-3	20	slightly	496(258)	365(184)	368(186)	40
2-4	20	slightly	489(254)	370(188)		40
2-5	19	none	504(262)	415(213)	415(213)	50
2-6	19	none	505(263)	415(213)		50
2-7	19	none	502(261)	450(232)	450(232)	70
2-8	19	none	498(259)	450(232)		70
2-9	19	none	500(260)	450(232)		70
2-10	19	none	502(261)	461(238)	454(234)	90
2-11	19	none	498(259)	450(232)		90
2-12	19	none	500(260)	450(232)		90
2-13	19	none	492(256)	465(241)	463(239)	130
2-14	19	none	500(260)	470(243)		130

TABLE 4.2.2

SURFACE: PRIMED METAL AND TOP COATED METAL

WITH BONDERITE 1415 PRETREATMENT

Average oven temperature: 450 °F (232 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	P.M.T. °F(°C)	Average (PMT) °F(°C)	R.S. (s)
2-15	19	total	451(233)	345(174)		50
2-16	19	total	450(232)	350(177)	350(177)	50
2-17	19	total	446(230)	360(182)		50
2-18	24	none	448(231)	380(193)	378(192)	70
2-19	24	none	450(232)	375(191)		70
2-20	24	none	453(234)	420(216)	420(216)	100
2-21	24	none	450(232)	420(216)		100
2-22	24	none	451(233)	420(216)	420(216)	130
2-23	24	none	451(233)	420(216)		130

TABLE 4.2.3

SURFACE: PRIMED METAL AND TOP COATED METAL

WITH BONDERITE 1415 PRETREATMENT

Average oven temperature: 408 °F (209°C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	P.M.T. °F(°C)	Average (PMT) °F(°C)	R.S. (s)
2-24	19	total	410(210)	345(174)		50
2-25	19	total	410(210)	345(174)	343(173)	50
2-26	19	total	410(210)	340(171)		50
2-27	24	none	410(210)	350(177)	345(174)	60
2-28	24	none	408(209)	340(171)		60
2-29	24	none	408(209)	365(185)		70
2-30	24	none	406(208)	355(179)	360(182)	70
2-31	24	none	403(206)	360(182)		70
2-32	24	none	406(208)	360(182)		70
2-33	24	none	410(210)	385(196)		100
2-34	24	none	410(210)	390(199)	387(197)	100
2-35	24	none	405(207)	385(196)		100
2-36	24	none	401(205)	390(199)		100
2-37	24	none	417(214)	400(204)	400(204)	130
2-38	24	none	415(213)	400(204)		130

TABLE 4.2.4

SURFACE: PRIMED METAL AND TOP COATED METAL

WITH BONDERITE 1414 PRETREATMENT

Average oven temperature: 498 °F (259 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	P.M.T. °F(°C)	Average (PMT) °F(°C)	R.S. (s)
2-39	22	none	507(264)	290(143)	320(160)	30
2-40	22	none	489(254)	330(166)		30
2-41	22	none	504(262)	340(171)		30
2-42	22	none	500(260)	405(207)	400(204)	50
2-43	22	none	500(260)	393(202)		50
2-44	22	none	486(252)	450(232)	450(232)	70
2-45	22	none	489(254)	450(232)		70
2-46	22	none	502(261)	475(246)	473(245)	130
2-47	22	none	505(263)	470(243)		130

TABLE 4.2.5

SURFACE: PRIMED METAL AND TOP COATED METAL

WITH BONDERITE 1414 PRETREATMENT

Average oven temperature: 455 °F (235 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	P.M.T. °F(°C)	Average (PMT) °F(°C)	R.S. (s)
2-48	24	none	451(233)	290(143)	290(143)	30
2-49	24	none	444(229)	290(143)		30
2-50	24	none	460(238)	340(171)	330(166)	50
2-51	24	none	457(236)	310(154)		50
2-52	24	none	457(236)	340(171)		50
2-53	24	none	462(239)	370(188)	371(188)	70
2-54	24	none	453(234)	372(189)		70
2-55	24	none	453(234)	420(216)	420(216)	100
2-56	24	none	459(237)	420(216)		100
2-57	24	none	459(237)	420(216)	425(218)	130
2-58	24	none	459(237)	430(221)		130

TABLE 4.2.6

SURFACE: PRIMED METAL AND TOP COATED METAL

WITH BONDERITE 1414 PRETREATMENT

Average oven temperature: 421 °F (216 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	P.M.T. °F(°C)	Average (PMT) °F(°C)	R.S. (s)
2-59	24	none	423(217)	340(171)	340(171)	60
2-60	24	none	419(215)	340(171)		60
2-61	24	none	421(216)	340(171)	343(173)	70
2-62	24	none	423(217)	345(174)		70
2-63	24	none	424(218)	390(199)	388(198)	100
2-64	24	none	419(215)	385(196)		100
2-65	24	none	419(215)	400(204)	400(204)	130
2-66	24	none	417(214)	400(204)		130

4.3. Experimental Curves

On the following pages the representation of peak metal temperature vs the residence time plots, for the five oven temperaturesare presented.

FIGURE 4.3.1

PEAK METAL TEMPERATURE (PMT) VS RESIDENCE TIME (RS), EXPERIMENTAL VALUES.

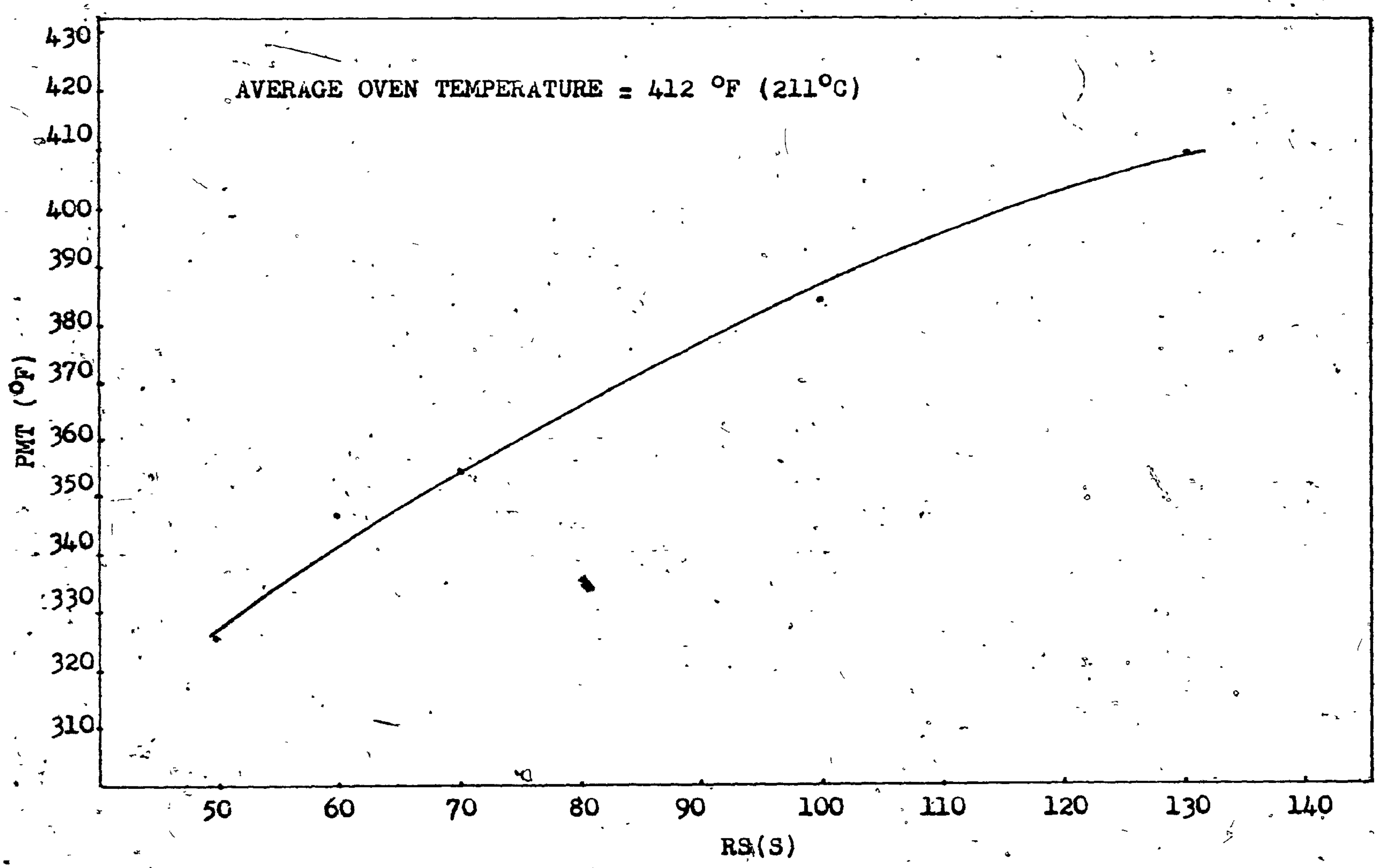


FIGURE 4.3.2

PEAK METAL TEMPERATURE (PMT) VS RESIDENCE TIME (RS), EXPERIMENTAL VALUES.

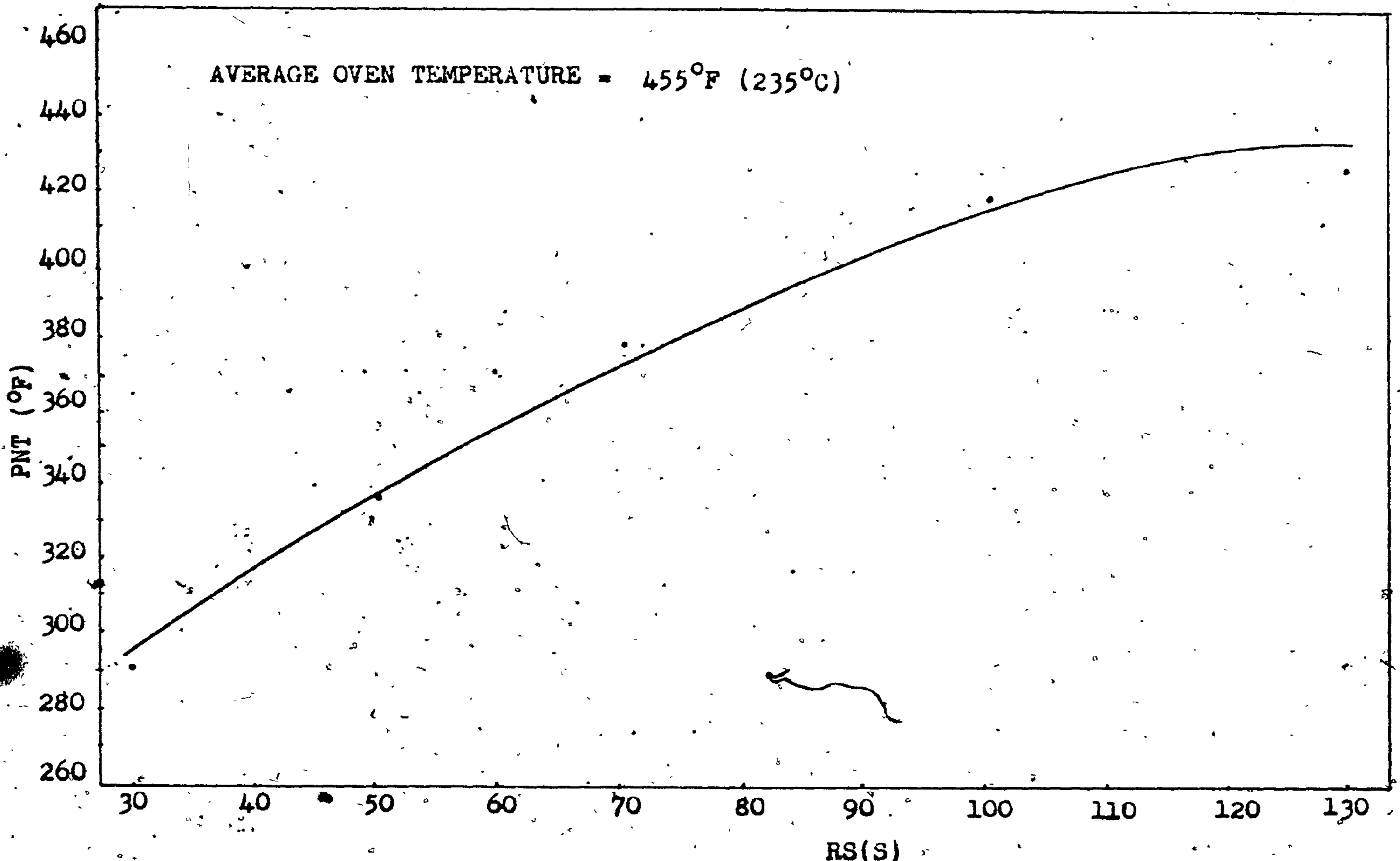


FIGURE 4.3.3

PEAK METAL TEMPERATURE (PMT) VS RESIDENCE TIME (RS), EXPERIMENTAL VALUES.

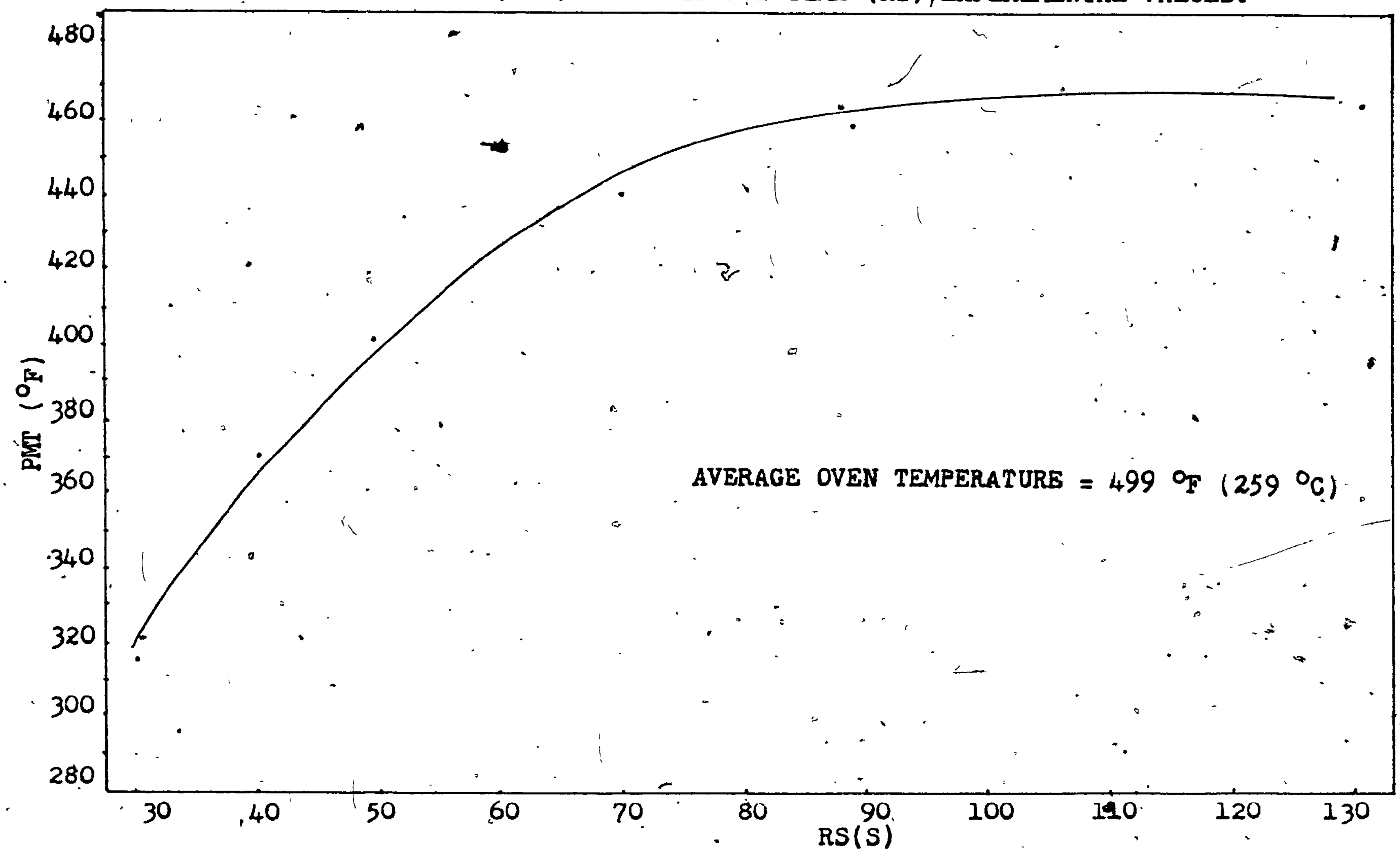


FIGURE 4.3.4

PEAK METAL TEMPERATURE (PMT) VS RESIDENCE TIME (RS), EXPERIMENTAL VALUES.

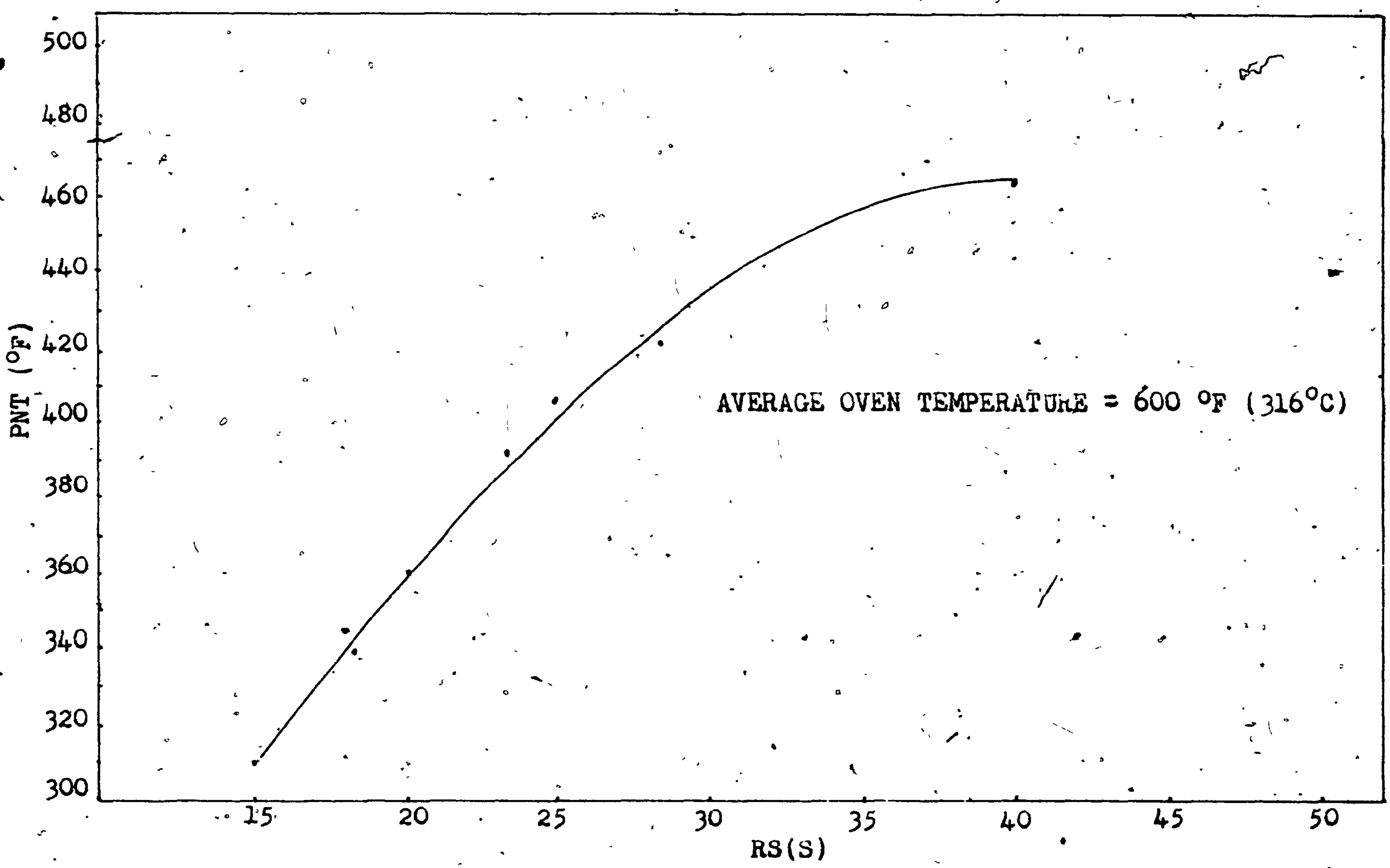
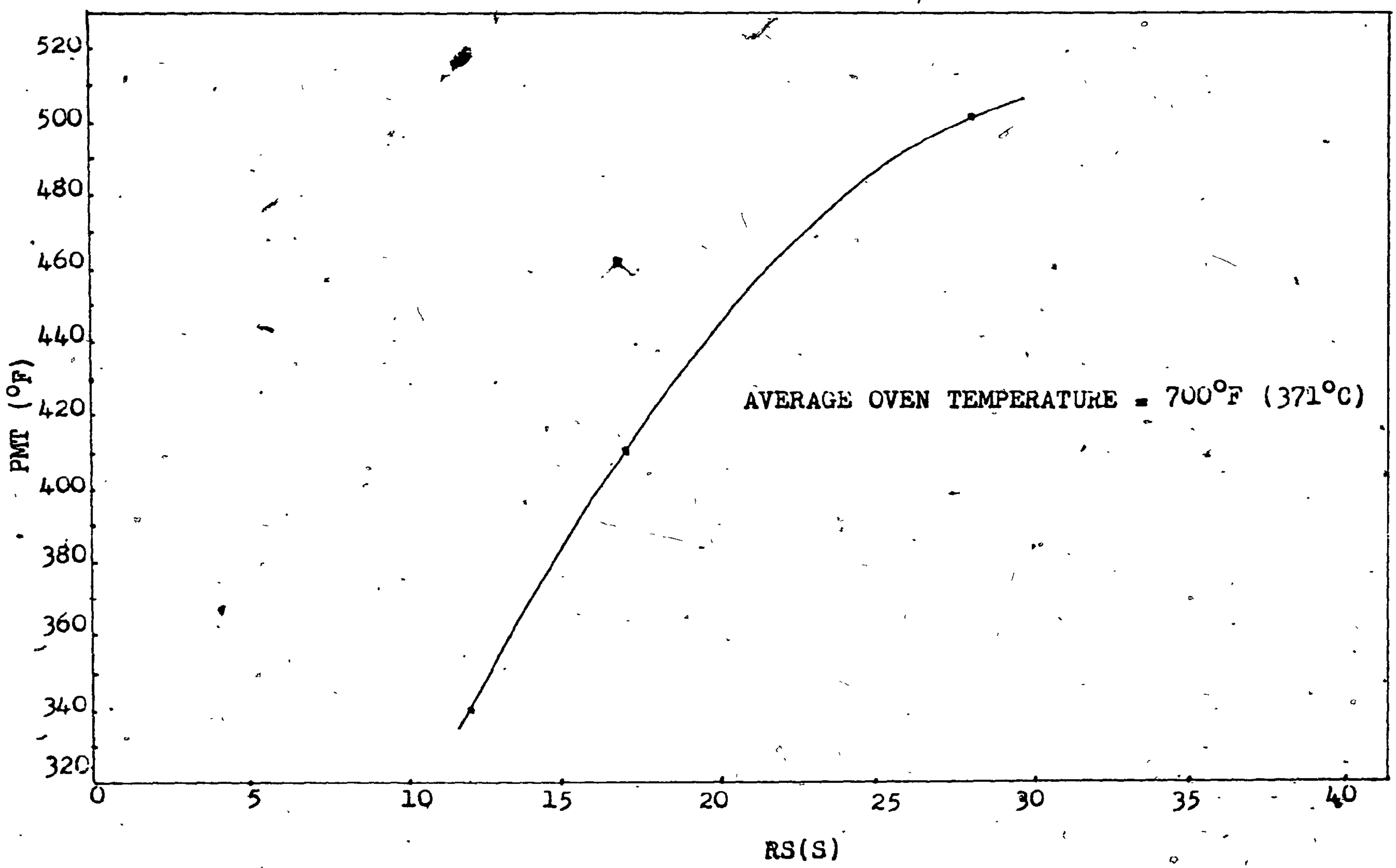


FIGURE 4.3.5

PEAK METAL TEMPERATURE (PMT) VS RESIDENCE TIME (RS) EXPERIMENTAL VALUES.



4.4. EFFECT OF PRIMER BAKING TEMPERATURE

TABLE 4.4.1

SURFACE: PRIMED METAL WITH BONDERITE 1415

Average oven temperature: 498 °F (259 °C)

Experiment number	O.T. °F(°C)	P.M.T. °F(°C)	R.S. (s)
4-1	498(259)	300(149)	30
4-2	496(258)	200(149)	30
4-3	496(258)	305(152)	30
4-4	496(258)	305(152)	30
4-5	500(260)	300(149)	30
4-6	496(258)	300(149)	30
4-7	500(260)	310(154)	30
4-8	500(260)	320(160)	30
4-9	502(262)	300(149)	30

TABLE 4.4.2

SURFACE: PRIMED METAL CURED AT APPROX. 308 °F (153 °C) AND TOP COAT AT DIFFERENT PMT WITH BONDERITE 1415 PRETREATMENT. THE PRIMER AND TOP COAT LAYERS APPLIED PERPENDICULAR TO ONE ANOTHER.

Average oven temperature: 504 °F (262 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	P.M.T. °F(°C)	Average (PMT) °F(°C)	R.S. (%)
4-10	23	total	500(260)	300(149)	300(149)	30
4-11	23	total	498(259)	300(149)		30
4-12	23	total	504(262)	300(149)	352(178)	40
4-13	23	total	504(262)	305(152)		40
4-14	23	none	502(261)	370(188)		40
4-15	23	none	504(262)	380(193)		40
4-16	23	none	507(264)	385(196)	380(193)	50
4-17	23	none	509(265)	375(191)		50
4-18	23	none	511(266)	425(218)		70

TABLE 4.4.3

SURFACE: PRIMED METAL WITH BONDERITE 1415

Average oven temperature: 495 °F (257 °C)

Experiment number	O.T. °F(°C)	P.M.T. °F(°C)	R.S. (s)
4-19	493(256)	365(185)	40
4-20	493(256)	365(185)	40
4-21	496(258)	370(188)	40
4-22	496(258)	375(191)	40
4-23	495(257)	380(193)	40
4-24	495(257)	380(193)	40
4-25	496(258)	365(185)	40
4-26	496(258)	365(185)	40

TABLE 4.4.4

SURFACE: PRIMED METAL CURED AT APPROX. 372 °F (189 °C) AND TOP COAT AT DIFFERENT PMT WITH BONDERITE 1415 PRETREATMENT. THE PRIMER AND TOP COAT LAYERS APPLIED PERPENDICULAR TO ONE ANOTHER.

Average oven temperature: 500 °F (260 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	P.M.T. °F(°C)	Average (PMT) °F(°C)	R.S. (s)
4-27	24	none	496(258)	320(160)	320(160)	30
4-28	24	none	496(258)	320(160)		30
4-29	24	none	502(261)	370(188)	370(188)	40
4-30	24	none	496(258)	370(188)		40
4-31	24	none	504(262)	395(202)	400(204)	50
4-32	24	none	505(263)	405(204)		50
4-33	24	none	505(263)	435(224)	430(221)	70
4-34	24	none	502(260)	425(218)		70

TABLE 4.4.5

SURFACE: PRIMED METAL WITH BONDERITE 1415

Average oven temperature: 502 °F (261 °C)

Experiment number	O.T. °F(°C)	P.M.T. °F(°C)	R.S. (s)
4-35	504(262)	405(207)	50
4-36	504(262)	405(207)	50
4-37	496(258)	405(207)	50
4-38	496(258)	405(207)	50
4-39	504(262)	405(207)	50
4-40	500(260)	405(207)	50
4-41	504(262)	400(204)	50
4-42	500(260)	400(204)	50
4-43	504(262)	400(204)	50
4-44	500(260)	400(204)	50

TABLE 4.4.6

SURFACE: PRIMED METAL CURED AT APPROX. 403 °F (206 °C) AND TOP COAT AT DIFFERENT PMT WITH BONDERITE 1415 PRETREATMENT. THE PRIMER AND TOP COAT LAYERS APPLIED PERPENDICULAR TO ONE ANOTHER.

Average oven temperature: 496 °F (258 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	P.M.T. °F(°C)	Average (PMT) °F(°C)	R.S. (s)
4-45	23	none	502(261)	300(149)	300(149)	30
4-46	23	none	500(260)	300(149)		30
4-47	23	none	495(257)	300(149)	300(149)	30
4-48	23	none	491(255)	300(149)		30
4-49	23	none	500(260)	370(188)	370(188)	40
4-50	23	none	500(260)	370(188)		40
4-51	23	none	500(260)	390(199)	398(203)	50
4-52	23	none	504(262)	405(207)		50
4-53	23	none	502(261)	440(227)	438(226)	70
4-54	23	none	500(260)	435(224)		70

TABLE 4.4.7

SURFACE: PRIMED METAL WITH BONDERITE 1415

Average oven temperature: 505 °F (263 °C)

Experiment number	O.T. °F(°C)	P.M.T. °F(°C)	R.S. (s)
4-55	505(263)	330(166)	30
4-56	505(263)	330(166)	30
4-57	505(263)	300(149)	30
4-58	505(263)	300(149)	30
4-59	507(264)	315(157)	30
4-60	507(264)	315(157)	30
4-61	504(262)	325(163)	30
4-62	504(262)	325(163)	30

TABLE 4.4.8.

SURFACE: PRIMED METAL CURED AT APPROX. 318 °F (159 °C) AND

TOP COAT AT DIFFERENT PMT WITH BONDERITE 1415 PRETREATMENT.

THE PRIMER AND TOP COAT LAYERS APPLIED PERPENDICULAR TO ONE ANOTHER.

Average oven temperature: 507 °F (264 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F (°C)	P.M.T. °F (°C)	Average (PMT) °F (°C)	R.S. (s)
4-63	23	slightly	504(262)	320(160)		30
4-64	23	slightly	504(262)	310(154)	317(159)	30
4-65	23	slightly	507(264)	320(160)		30
4-66	23	none	502(261)	380(193)	375(191)	40
4-67	23	none	507(264)	370(188)		40
4-68	23	none	511(266)	405(207)	400(204)	50
4-69	23	none	505(263)	395(202)		50
4-70	23	none	514(268)	450(232)		70

TABLE 4.4.9

SURFACE: PRIMED METAL WITH BONDERITE 1415

Average oven temperature: 507 °F (264 °C)

Experiment number	O.T. °F(°C)	P.M.T. °F(°C)	R.S. (s)
4-71	505(263)	380(183)	40
4-72	505(263)	380(183)	40
4-73	509(265)	395(202)	40
4-74	509(265)	395(202)	40
4-75	507(264)	370(188)	40
4-76	507(264)	370(188)	40
4-77	505(263)	365(185)	40
4-78	505(263)	365(185)	40

TABLE 4.4.10

SURFACE: PRIMED METAL CURED AT APPROX. 378 °F (192°C) AND TOP COAT AT DIFFERENT PMT WITH BONDERITE 1415 PRETREATMENT. PRIMER AND TOP COAT LAYERS BOTH APPLIED IN THE SAME DIRECTION.

Average oven temperature: 507 °F (264 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	P.M.T. °F(°C)	Average (PMT) °F(°C)	R.S. (s)
4-79	23	none	504(262)	300(149)		30
4-80	23	none	507(264)	305(152)	312(156)	30
4-81	23	none	505(263)	330(166)		30
4-82	23	none	511(266)	370(188)	378(192)	40
4-83	23	none	507(264)	385(196)		40
4-84	23	none	511(266)	415(213)	415(213)	50
4-85	23	none	509(265)	415(213)		50
4-86	23	none	505(263)	450(232)		70

4.5 Effect of Chemicals

TABLE 4.5.1

SURFACE: PRIMED METAL WITH BONDERITE 1415 PRETREATMENT

Average oven temperature: 505 °F (263) °C

Experiment number	O.T. °F (°C)	P.M.T. °F (°C)	R.S. (s)
6-1	505 (263)	300 (149)	30
6-2	505 (263)	300 (149)	30
6-3	507 (264)	315 (157)	30
6-4	505 (263)	330 (166)	30
6-5	505 (263)	330 (166)	30
6-6	504 (262)	325 (163)	30
6-7	504 (262)	325 (163)	30

TABLE 4.5.2

SURFACE: PRIMED METAL CURED AT APPROXIMATELY 318 °F (159 °C)
AND TOP COAT AT DIFFERENT PMT WITH BONDERITE 1415 PRETREATMENT

Soak test: Nitric acid solution, pH = 1.20

Average oven temperature: 505 °F (263 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	P.M.T. °F(°C)	Average (PMT) °F(°C)	R.S. (s)
6-8	18	completely peeled	504(262)	320(160)		30
6-9	18	completely peeled	504(262)	310(154)	317(158)	30
6-10	18	completely peeled	507(264)	320(160)		30
6-11	18	completely peeled	502(261)	375(191)	370(188)	40
6-12	18	completely peeled	507(264)	365(185)		40
6-13	18	completely peeled	511(266)	405(207)	400(204)	50
6-14	18	completely peeled	505(263)	395(202)		50

TABLE 4.5.3

SURFACE: PRIMED METAL CURED AT APPROXIMATELY 318 °F (159 °C) AND TOP COAT AT DIFFERENT PMT WITH BONDERITE 1415 PRETREATMENT

Soak test: Nitric acid solution; pH - 2.00

Average oven temperature: 505 °F (263 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	P.M.T. °F(°C)	Average (PMT) °F(°C)	R.S. (s)
6-15	18	slightly	504(262)	320(160)		30
6-16	18	slightly	504(262)	310(154)	317(158)	30
6-17	18	slightly	507(264)	320(160)		30
6-18	18	none	504(261)	375(191)	370(188)	40
6-19	18	none	507(264)	365(185)		40
6-20	18	none	501(266)	405(207)	400(204)	50
6-21	18	none	505(263)	395(202)		50

TABLE 4.5.4

SURFACE: PRIMED METAL CURED AT APPROXIMATELY 318 °F (159 °C) AND TOP COAT AT DIFFERENT PMT WITH BONDERITE 1415 PRETREATMENT

Soak test: Nitric acid solution, pH = 3.10

Average oven temperature: 505 °F (263 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	P.M.T. °F(°C)	Average (PMT) °F(°C)	R.S. (s)
6-22	18	none	504(262)	320(160)		30
6-23	18	none	504(262)	310(154)	317(158)	30
6-24	18	none	507(264)	320(160)		30
6-25	18	none	504(261)	375(191)	370(188)	40
6-26	18	none	507(264)	365(185)		40
6-27	18	none	511(266)	405(207)	400(204)	50
6-28	18	none	505(263)	395(202)		50

TABLE 4.5.5

SURFACE: PRIMED METAL CURED AT APPROXIMATELY 318 °F (159 °C) AND TOP COAT AT DIFFERENT PMT WITH BONDERITE 1415 PRETREATMENT

Soak test: Nitric acid solution, pH = 3.80

Average oven temperature: 505 °F (263 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	PMT °F(°C)	Average (PMT) °F(°C)	R.S. (s)
6-29	18	none	504(262)	320(160)		30
6-30	18	none	504(262)	310(154)	317(158)	30
6-31	18	none	507(264)	320(160)		30
6-32	18	none	504(261)	375(191)	370(188)	40
6-33	18	none	507(264)	365(185)		40
6-34	18	none	511(266)	405(207)	400(204)	50
6-35	18	none	505(263)	395(202)		50

TABLE 4.5.6

SURFACE: PRIMED METAL WITH BONDERITE 1415

PRETREATMENT

Average oven temperature: 491 °F (255°C)

Experiment number	O.T. °F(°C)	P.M.T. °F(°C)	R.S. (s)
6-36	482(250)	330(166)	30
6-37	482(250)	330(166)	30
6-38	495(257)	325(163)	30
6-39	495(257)	325(163)	30
6-40	496(258)	330(166)	30
6-41	496(258)	330(166)	30
6-42	493(256)	330(166)	30
6-43	493(256)	330(166)	30

TABLE 4.5.7

SURFACE: PRIMED METAL CURED AT APPROXIMATELY 329 °F (165 °C) AND TOP COAT AT DIFFERENT PMT WITH BONDERITE 1415 PRETREATMENT

Soak test: Sulfuric acid solution, pH = 1.30

Average oven temperature: 489 °F (254 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	PMT °F(°C)	Average (PMT) °F(°C)	R.S. (s)
6-44	22	complete	482(250)	~~330(166)~~	335(168)	30
6-45	22	complete	495(257)	340(171)		30
6-46	22	complete	486(252)	370(188)	370(188)	40
6-47	22	complete	489(254)	370(188)		
6-48	22	complete	491(255)	400(204)	400(204)	50
6-49	22	complete	491(255)	400(204)		50

TABLE 4.5.8

SURFACE: PRIMED METAL CURED AT APPROXIMATELY 329 °F (165 °C) AND TOP COAT AT DIFFERENT PMT WITH BONDERITE 1415 PRETREATMENT

Soak test: Sulfuric acid solution, pH = 2.00

Average oven temperature: 489 °F (254 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	PMT °F(°C)	Average (PMT) °F(°C)	R.S. (s)
6-50	22	total	482(250)	330(166)	335(168)	30
6-51	22	total	495(257)	340(171)		30
6-52	22	total	486(252)	370(188)	370(188)	40
6-53	22	total	489(254)	370(188)		40
6-54	22	slightly	491(255)	400(204)	400(204)	50
6-55	22	slightly	491(255)	400(204)		50

TABLE 4.5.9

SURFACE: PRIMED METAL CURED AT APPROXIMATELY 329 °F (165 °C) AND TOP COAT AT DIFFERENT PMT WITH BONDERITE 1415 PRETREATMENT

Soak test: Sulfuric acid solution, pH = 2.60

Average oven temperature: 489 °F (254 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	PMT °F(°C)	Average (PMT) °F(°C)	R.S. (s)
6-56	22	total	482(250)	330(166)	335(168)	30
6-57	22	total	495(257)	340(171)		30
6-58	22	slightly	486(252)	370(188)	370(188)	40
6-59	22	slightly	489(254)	370(188)		40
6-60	22	none	491(255)	400(204)	400(204)	50
6-61	22	none	491(255)	400(204)		50

TABLE 4.5.10

SURFACE: PRIMED METAL CURED AT APPROXIMATELY 329 °F (165 °C) AND TOP COAT AT DIFFERENT PMT WITH BONDERITE 1415 PRETREATMENT

Soak test: Sulfuric acid solution, pH = 3.60

Average oven temperature: 489 °F (254 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	PMT °F(°C)	Average (PMT) °F(°C)	R.S. (s)
6-62	22	slightly	482(250)	330(166)	335(168)	30
6-63	22	slightly	495(257)	340(171)		30
6-64	22	none	486(252)	370(188)	370(188)	40
6-65	22	none	489(254)	370(188)		40
6-66	22	none	491(255)	400(204)	400(204)	50
6-67	22	none	491(255)	400(204		50

TABLE 4.5.11

SURFACE: PRIMED METAL WITH BONDERTIE 1414 PRETREATMENT

Average oven temperature: 503 °F (262 °C)

Experiment number	O.T. °F(°C)	P.M.T. °F(°C)	R.S. (s)
6-68	507(264)	340(171)	30
6-69	500(260)	330(166)	30
6-70	502(261)	320(160)	30
6-71	498(259)	330(166)	30
6-72	505(263)	320(160)	30
6-73	507(264)	310(155)	30

TABLE 4.5.12

SURFACE: PRIMED METAL CURED AT APPROXIMATELY 325 °F (163 °C) AND TOP COAT AT DIFFERENT PMT WITH BONDERITE 1414 PRETREATMENT

Soak test: Nitric acid solution, pH = 1.30

Average oven temperature: 491 °F (255 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	PMT °F(°C)	Average (PMT) °F(°C)	R.S. (s)
6-74	23	completely peeled	482(250)	340(171)	340(171)	30
6-75	23	completely peeled	493(256)	340(171)		30
6-76	23	completely peeled	489(254)	380(193)	375(191)	40
6-77	23	completely peeled	491(255)	370(188)		40
6-78	23	completely peeled	496(258)	405(207)	407(208)	50
6-79	23	completely peeled	498(259)	410(210)		50

TABLE 4.5.13

SURFACE: PRIMED METAL CURED AT APPROXIMATELY 325 °F (163 °C) AND TOP COAT AT DIFFERENT PMT WITH BONDERITE 1414 PRETREATMENT

Soak test: Nitric acid solution, pH = 2.00

Average oven temperature: 491 °F (255 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	PMT °F(°C)	Average (PMT) °F(°C)	R.S. (s)
6-80	23	completely peeled	482(250)	340(171)	340(171)	30
6-81	23	completely peeled	493(256)	340(171)		30
6-82	23	total	489(254)	380(193)	375(191)	40
6-83	23	total	491(255)	370(188)		40
6-84	23	total	496(258)	405(207)	407(208)	50
6-85	23	total	498(259)	410(210)		50

TABLE 4.5.14

SURFACE: PRIMED METAL CURVED AT APPROXIMATELY 325 °F (163 °C) AND TOP COAT AT DIFFERENT PMT WITH BONDERITE 1414 PRETREATMENT

Soak test: Nitric acid solution, pH = 2.75

Average oven temperature: 491 °F (255 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	PMT °F(°C)	Average (PMT) °F(°C)	R.S. (s)
6-86	23	none	482(250)	340(171)	340(171)	30
6-87	23	none	493(256)	340(171)		30
6-88	23	none	489(254)	380(193)	375(191)	40
6-89	23	none	491(255)	370(188)		40
6-90	23	none	496(258)	405(207)	407(208)	50
6-91	23	none	498(259)	410(210)		50

TABLE 4.5.15

SURFACE: PRIMED METAL CURED AT APPROXIMATELY 325 °F (163 °C) AND TOP COAT AT DIFFERENT PMT WITH BONDERITE 1414 PRETREATMENT

Soak test: Nitric acid solution, pH = 3.80

Average oven temperature: 491 °F (255 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	PMT °F(°C)	Average (PMT) °F(°C)	R.S. (s)
6-92	23	none	482(250)	340(171)	340(171)	30
6-93	23	none	493(256)	340(171)		30
6-94	23	none	489(254)	380(193)	375(191)	40
6-95	23	none	491(255)	370(188)		40
6-96	23	none	496(258)	405(207)	407(208)	50
6-97	23	none	498(259)	410(210)		50

TABLE 4.5.16

SURFACE: PRIMED METAL WITH BONDERITE 1414

Average oven temperature: 500 °F (260) °C)

Experiment number	O.T. °F(°C)	P.M.T. °F(°C)	R.S. (s)
6-99	500(260)	305(152)	30
6-100	502(261)	300(149)	30
6-101	499(259)	300(149)	30
6-102	502(261)	310(154)	30
6-103	500(260)	305(152)	30
6-104	497(258)	300(149)	30

TABLE 4.5.17

SURFACE: PRIMED METAL CURED AT APPROXIMATELY 303 °F (151 °C) AND TOP COAT AT DIFFERENT PMT WITH BONDERITE 1414 PRETREATMENT

Soak test: Sulfuric acid solution, pH = 1.20

Average oven temperature: 491 °F (255 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	P.M.T. °F(°C)	Average (PMT) °F(°C)	R.S. (s)
6-105	24	completely peeled	483(251)	330(166)	335(168)	30
6-106	24	completely peeled	491(255)	340(171)		30
6-107	24	completely peeled	491(255)	365(185)	365(185)	40
6-108	24	completely peeled	489(254)	365(185)		40
6-109	24	completely peeled	495(257)	400(204)	403(206)	50
6-110	24	completely peeled	500(260)	405(207)		50

TABLE 4.5.18

SURFACE: PRIMED METAL CURED AT APPROXIMATELY 303 °F (151 °C) AND TOP COAT AT DIFFERENT PMT WITH BONDERITE 1414 PRETREATMENT

Soak test: Sulfuric acid solution, pH = 2.00

Average oven temperature: 491 °F (255 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	P.M.T. °F(°C)	Average (PMT) °F(°C)	R.S. (s)
6-111	24	completely peeled	483(251)	330(166)	335(168)	30
6-112	24	completely peeled	491(255)	340(171)		30
6-113	24	completely peeled	491(255)	365(185)	365(185)	40
6-114	24	completely peeled	489(254)	365(185)		40
6-115	24	completely peeled	495(257)	400(204)	403(206)	50
6-116	24	completely peeled	500(260)	405(207)		50

TABLE 4.5.19

SURFACE: PRIMED METAL CURED AT APPROXIMATELY 303 ^oF (151 ^oC) AND TOP COAT AT DIFFERENT PMT WITH BONDERITE 1414 PRETREATMENT

Soak test: Sulfuric acid solution, pH = 2.80

Average oven temperature: 491 ^oF (255 ^oC)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. $^oF(^oC)$	P.M.T. $^oF(^oC)$	Average (PMT) $^oF(^oC)$	R.S. (s)
6-117	24	none	483(251)	330(166)	335(168)	30
6-118	24	none	491(255)	340(171)		30
6-119	24	none	491(255)	365(185)	365(185)	40
6-120	24	none	489(254)	365(185)		40
6-121	24	none	495(257)	400(204)	403(206)	50
6-122	24	none	500(260)	405(207)		50

TABLE 4.5.20

SURFACE: PRIMED METAL CURED AT APPROXIMATELY 303 ^{o}F (151 ^{o}C) AND TOP COAT AT DIFFERENT PMT WITH BONDERITE 1414 PRETREATMENT

Soak test: Sulfuric acid solution, pH = 3.60

Average oven temperature: 491 ^{o}F (255 ^{o}C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. $^{o}F(^{o}C)$	P.M.T. $^{o}F(^{o}C)$	Average (PMT) $^{o}F(^{o}C)$	R.S. (s)
6-123	24	none	483(251)	330(166)	335(168)	30
6-124	24	none	491(255)	340(171)		30
6-125	24	none	491(255)	365(185)	365(185)	40
6-126	24	none	489(254)	365(185)		40
6-127	24	none	495(257)	400(204)	403(206)	50
6-128	24	none	500(260)	405(207)		50

TABLE 4.5.21

SURFACE: PRIMED METAL WITH BONDERITE 1415

Average oven temperature: 500 °F (260 °C)

Experiment number	O.T. °F(°C)	P.M.T. °F(°C)	R.S. (s)
6-129	502(261)	315(157)	30
6-130	502(261)	310(154)	30
6-131	500(260)	305(152)	30
6-132	496(258)	315(157)	30
6-133	498(259)	318(159)	30
6-134	498(259)	320(160)	30

TABLE 4.5.22

SURFACE: PRIMED METAL CURED AT APPROXIMATELY 314 °F (157 °C) AND TOP COAT AT DIFFERENT PMT WITH BONDERITE 1415 PRETREATMENT

Soak test: Sodium hydroxide solution, pH = 8.20

Average oven temperature: 500 °F (260 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	P.M.T. °F(°C)	Average (PMT) °F(°C)	R.S. (s)
6-135	23	slightly	504(262)	310(154)	315(157)	30
6-136	23	slightly	502(261)	320(160)		30
6-137	23	none	500(260)	365(185)	368(187)	40
6-138	23	none	498(259)	370(188)		40
6-139	23	none	498(259)	395(202)	398(203)	50
6-140	23	none	502(261)	400(204)		50

TABLE 4-5.23

SURFACE: PRIMED METAL CURED AT APPROXIMATELY 314 °F (157 °C) AND TOP COAT AT DIFFERENT PMT WITH BONDERITE 1415 PRETREATMENT

Soak test: Sodium hydroxide solution, pH = 9.60

Average oven temperature: 500 °F (260 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	P.M.T. °F(°C)	Average (PMT) °F(°C)	R.S. (s)
6-141	23	slightly	504(262)	310(154)	315(157)	30
6-142	23	slightly	502(261)	320(160)		30
6-143	23	none	500(260)	365(185)	368(187)	40
6-144	23	none	498(259)	370(188)		40
6-145	23	none	498(259)	395(202)	398(203)	50
6-146	23	none	502(261)	400(204)		50

TABLE 4.5.24

SURFACE: PRIMED METAL CURED AT APPROXIMATELY 314 °F (157 °C)

AND TOP COAT AT DIFFERENT PMT WITH BONDERITE 1415 PRETREATMENT

Soak test: Sodium hydroxide solution, pH = 10.70

Average oven temperature: 500 °F (260 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	P.M.T. °F(°C)	Average (PMT) °F(°C)	R.S. (s)
6-147	23	slightly	504(262)	310(154)	315(157)	30
6-148	23	slightly	502(261)	320(160)		30
6-149	23	none	500(260)	365(185)	368(187)	40
6-150	23	none	498(259)	370(188)		40
6-151	23	none	498(259)	395(202)	398(203)	50
6-152	23	none	502(261)	400(204)		50

TABLE 4.5.25

SURFACE: PRIMED METAL CURED AT APPROXIMATELY 314 °F (157 °C) AND TOP COAT AT DIFFERENT PMT WITH BONDERITE 1415 PRETREATMENT

Soak test: Potassium hydroxide, pH = 8.15

Average oven temperature: 500 °F (260 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	P.M.T. °F(°C)	Average (PMT) °F(°C)	R.S. (s)
6-153	23	slightly	504(262)	310(154)	315(157)	30
6-154	23	slightly	502(261)	320(160)		30
6-155	23	none	500(260)	365(185)	368(187)	40
6-156	23	none	498(259)	370(188)		40
6-157	23	none	498(259)	395(202)	398(203)	50
6-158	23	none	502(261)	400(204)		50

TABLE 4.5.26

SURFACE: PRIMED METAL CURED AT APPROXIMATELY 314 °F (157 °C) AND TOP COAT AT DIFFERENT PMT WITH BONDERITE 1415 PRETREATMENT

Soak test: Potassium hydroxide, pH = 9.10

Average oven temperature: 500 °F (260 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	P.M.T. °F(°C)	Average (PMT) °F(°C)	R.S. (s)
6-159	23	slightly	504(262)	310(154)	315(157)	30
6-160	23	slightly	502(261)	320(160)		30
6-161	23	none	500(260)	365(185)	368(187)	40
6-162	23	none	498(259)	370(188)		40
6-163	23	none	498(259)	395(202)	398(203)	50
6-164	23	none	502(261)	400(204)		50

TABLE 4.5.27

SURFACE: PRIMED METAL CURED AT APPROXIMATELY 314 °F (157 °C) AND TOP COAT AT DIFFERENT PMT WITH BONDERITE 1415 PRETREATMENT

Soak test: Potassium hydroxide solution, pH = 10.90

Average oven temperature: 500 °F (260 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	P.M.T. °F(°C)	Average (PMT) °F(°C)	R.S. (s)
6-165	23	slightly	504(262)	310(154)	315(157)	30
6-166	23	slightly	502(261)	320(160)		30
6-167	23	none	500(260)	365(185)	368(187)	40
6-168	23	none	498(259)	370(188)		40
6-169	23	none	498(259)	395(202)	398(203)	50
6-170	23	none	502(261)	400(204)		50

TABLE 4.5.28

SURFACE: PRIMED METAL WITH BONDERITE 1414 PRETREATMENT

Average ovent temperature: 500 °F (260 °C)

Experiment number	O.T. °F.(°C)	P.M.T. °F(°C)	R.S. (s)
6-171	504(262)	320(160)	30
6-172	502(261)	310(154)	30
6-173	498(259)	300(149)	30
6-174	500(260)	325(163)	30
6-175	502(261)	310(154)	30
6-176	496(258)	320(160)	30

TABLE 4.5.29

SURFACE: PRIMED METAL CURED AT APPROXIMATELY 314 °F (157 °C) AND TOP COAT AT DIFFERENT PMT WITH BONDERITE 1414 PRETREATMENT

Soak test: Sodium hydroxide solution, pH = 8.10

Average oven temperature: 502 °F (261 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	P.M.T. °F(°C)	Average (PMT) °F(°C)	R.S. (s)
6-177	22	none	504(262)	310(154)	315(158)	30
6-178	22	none	500(260)	320(160)		30
6-179	22	none	502(261)	375(191)	380(193)	40
6-180	22	none	507(264)	385(196)		40
6-181	22	none	498(259)	400(204)	403(206)	50
6-182	22	none	500(260)	405(207)		50

TABLE 4.5.30

SURFACE: PRIMED METAL CURED AT APPROXIMATELY 314 °F (157 °C) AND TOP COAT AT DIFFERENT PMT WITH BONDERITE 1414 PRETREATMENT

Soak test: Sodium hydroxide solution, pH = 9.50

Average oven temperature: 502 °F (261 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	P.M.T. °F(°C)	Average (PMT) °F(°C)	R.S. (s)
6-183	22	none	504(262)	310(154)	315(158)	30
6-184	22	none	500(260)	320(160)		30
6-185	22	none	502(261)	375(191)	380(193)	40
6-186	22	none	507(262)	385(196)		40
6-187	22	none	498(259)	400(204)	403(206)	50
6-188	22	none	500(260)	405(207)		50

TABLE 4-5.31

SURFACE: PRIMED METAL CURED AT APPROXIMATELY 314 °F (157 °C)

AND TOP COAT AT DIFFERENT PMT WITH BONDERITE 1414 PRETREATMENT

Soak test: Sodiumhydroxide solution, pH = 10.80

Average oven temperature: 502 °F (261 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	P.M.T. °F(°C)	Average (PMT) °F(°C)	R.S. (s)
6-189	22	slightly	504(262)	310(154)	315(158)	30
6-190	22	slightly	500(260)	320(160)		30
6-191	22	none	502(261)	375(191)	380(192)	40
6-192	22	none	5[illegible](264)	385(196)		40
6-193	22	none	498(259)	400(204)	403(206)	50
6-194	22	none	500(260)	405(207)		50

TABLE 4.5.32

SURFACE: PRIMED METAL WITH BONDERITE 1414 PRETREATMENT

Average oven temperature: 502 °F (261 °C)

Experiment number	O.T. °F(°C)	P.M.T. °F(°C)	R.S. (s)
6-195	505(263)	300(149)	30
6-196	500(260)	330(166)	30
6-197	498(259)	310(154)	30
6-198	504(262)	325(163)	30
6-199	502(261)	315(157)	30
6-200	505(263)	320(160)	30

TABLE 4.5.33

SURFACE: PRIMED METAL CURED AT APPROXIMATELY 317 °F (159 °C) AND TOP COAT AT DIFFERENT PMT WITH BONDERITE 1414 PRETREATMENT

Soak test: Potassium hydroxide solution, pH = 8.30

Average oven temperature: 498 °F (259 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	P.M.T. °F(°C)	Average (PMT) °F(°C)	R.S. (s)
6-201	24	none	498(259)	325(163)	323(162)	30
6-202	24	none	496(258)	320(160)		30
6-203	24	none	498(259)	375(191)	375(191)	40
6-204	24	none	500(260)	375(191)		40
6-205	24	none	495(257)	400(204)	397(203)	50
6-206	24	none	502(261)	395(202)		50

TABLE 4.5.34

SURFACE: PRIMED METAL CURED AT APPROXIMATELY 317 °F (159 °C) AND TOP COAT AT DIFFERENT PMT WITH BONDERITE 1414 PRETREATMENT

Soak test: Potassium hydroxide solution, pH = 9.60

Average oven temperature: 498 °F (259 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	P.M.T. °F(°C)	Average (PMT) °F(°C)	R.S. (s)
6-207	24	none	498(259)	325(163)	323(162)	30
6-208	24	none	496(259)	320(160)		30
6-209	24	none	498(259)	375(191)	375(191)	40
6-210	24	none	500(260)	375(191)		40
6-211	24	none	495(257)	400(204)	397(203)	50
6-212	24	none	502(261)	395(202)		50

TABLE 4.5.35

SURFACE: PRIMED METAL CURED AT APPROXIMATELY 317 °F (159 °C) AND TOP COAT AT DIFFERENT PMT WITH BONDERITE 1414 PRETREATMENT

Soak test: Potassium hydroxide solution, pH = 10.80

Average oven temperature: 498 °F (259 °C)

Experiment number	Soaking time (hrs)	Extent of failure	O.T. °F(°C)	P.M.T. °F(°C)	Average (PMT) °F(°C)	R.S. (s)
6-213	24	none	498(259)	325(163)	323(162)	30
6-214	24	none	496(258)	320(160)		30
6-215	24	none	498(259)	375(191)	375(191)	40
6-216	24	none	500(260)	375(191)		40
6-217	24	none	495(257)	400(204)	397(203)	50
6-218	24	none	502(261)	395(202)		50

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APPENDIX 1

The quality control of coated aluminium strips requires that some performance tests be carried out. They include: 1) hardness; 2) impact resistance; 3) ductility; 4) thickness measurements; 5) MEK rub test.

1) The hardness of a material is its resistance to indentation and is frequently related to its tensile strength. The hardness of a coating may be measured when attached to the metals or on its own and it should be noted that many coatings can be markedly harder than the substrate surface (e.g.chromium and nickel on copper or plastics). There are, however, difficulties involved in determining the hardness of thin coatings, particularly with soft coating materials on a hard substrate.
   Hardness tests in general are performed by compressing a hard indentor of accurately known geometry under a predeterminated load for a given time onto the test surface. After partial or complete removal of the load, the size of the indentation is measured and the hardness calculated. Several types of hardness tests are in current use and these include the Vickers, Brinel, Rockwell, Knoop and Shore methods, and various scratch tests.

   A rather simpler approach to hardness testing involves scratching the surface with diamond tipped pencils and the width of the scratch produced is a measure of the surface hardness. The hardness can be expressed as the load (in grams) required to produce a scratch of specified width. Alternatively, pencils with tips of different hardnesses can be drawn over the surface and the hardness assessed by a scratch/no scratch criterion.

2) A standard method (incorporated into many standards and specifications) is the free-falling impact test. A solid metal rod with a hemispherical head, of known weight, is allowed to fall under its own weight from a predetermined but adjustable height on to the coated surface of the specimen. After impact, the coating is inspected for cracking.

Impact tests are essentially qualitative in nature but are very useful for comparative assessments and for selection purposes.

3) Two broad categories of coating thickness measurement techniques are used, namely destructive and non-destructive. we have; a) microsectional examination by means of a microscopic point; b) weight change methods (consist of an increase in component weight for non-surface areas after coating), and c) solution methods.

Among the non-destructive techniques we have: a) Dimensional change (the measurement of the specimen's dimensions before and after coatings). b) Depth gauge (it is used for non-metallic (polymeric) coatings. It is measured by means of depth gauges, the simplest being a set of combs with teeth at different heights from the base). c) Magnetic gauges - they are basically either mechanically or flux measuring in operation. The simplest device, usually pencil shaped, consists of a small calibrated magnet attached to a spring. Where applied to a ferrous surface coated with a non-metallic material, the device measures the force required to pull off the magnet from the component. The extension of the spring, or mechanical force, is inversely proportional to the thickness of the coatings and the device is generally calibrated directly in thickness.

Still greater accuracy can be achieved with flux meters which employ a permanent magnet but measure the magnetic flux (which varies with the proximity of the ferrous substrate) across an internal air gap. A pointer, attached to an armature located in an air gap, provides a direct indication of the coating thickness. Accuracies of 95% are possible.

It is possible to induce eddy currents within solid conductors by rapidly changing the magnetic flux. This is usually achieved by means of high frequency currents passing through a coil or conductor situated over the specimen which induces large currents in the specimen. By using high frequencies, the induced or eddy currents can be constrained within quite thin surface layers and the magnitude of the eddy current will be proportional to the conductivity of the layer. By this means, the thickness of conductive and non-conductive coatings can be measured on both ferrous and non-ferrous bases. The instrument can be calibrated to provide direct measurements of the coating thickness. Several eddy current detectors are commercially available, between them the Permascope Eddy Current Thickness Gauge.

4) Ductility or elongation of coatings on metals is commonly assessed by bend tests around mandrels of specified diameters. The specimen are bent through 180° around mandrels of decreasing diameter until cracking is observed. The ductility is then calculated by means of relationship

$$\text{elongation} = 100 \left(\frac{t}{2R - t}\right)$$

where t = the thickness of the specimen

and r = the radius of curvature of the smallest diameter mandrel around which the specimen can be bent without cracking.

In its simplest form the ductility tests are carried out by simple bending of the metal in a bending machine. After the bending, the coating is inspected for cracking.

5) MEK rub test

This test is an indication of the fact that the paint film is well cured. It involves applying methyl, ethyl Ketone (MEK) solution on the surface of the plate. Some values are presented on(Table 1).

Part 1.

TABLE 1

A. TOP COATED FILMS

Experiment number	Rubs (MEK)	Thickness (mm)	Bend test (16 gauge mild gauge	Ball test (30 lb impact force inch lb)
1-20	6	0.88	no failure	no failure
1-21	5	0.92	" "	" "
1-26	20+	0.88	" "	" "
1-27	18	0.90	" "	" "
1-28	20+	0.96	" "	" "
1-29	20+	0.94	" "	" "
1-30	30+	0.86	" "	" "
4-11	5	0.93	" "	" "
4-12	5	0.91	" "	" "

Part 2.

TABLE 1

A. TOP COATED FILMS

Experiment number	Rubs (MEK)	Thickness (mm)	Bend test (16 gauge mild gauge	Ball test (30 lb impact force inch lb)
4-13	5	0.92	no failure	no failure
4-14	30+	0.92	slight failure	" "
4-15	30+	0.88	no failure	" "
4-16	30+	0.88	" "	" "
4-17	30+	0.94	slight failure	" "
4-19	30+	0.92	" "	" "
4-27	10	0.84	slight failure	slight failure
4-28	12	0.90	" "	" "
4-29	30+	0.89	" "	" "
4-30	30+	0.90	no failure	no failure

Part 3.

TABLE 1

A. TOP COATED FILMS

Experiment number	Rubs (MEK)	Thickness (mm)	Bend test (16 gauge mild gauge	Ball test (30 lb impact force inch lb)
4-31	35+	0.93	no failure	no failure
4-32	40+	0.92	" "	" "
4-33	40+	0.94	" "	" "
4-36	45+	0.84	slight failure	" "
4-79	5	0.96	slight failure	slight failure
4-80	5	0.90	" "	" "
4-81	7	0.80	" "	" "
4-82	20+	0.91	" "	no failure
4-83	25+	0.94	" "	" "

Part 4.

TABLE 1

A. TOP COATED FILMS

Experiment number	Rubs (MEK)	Thickness (mm)	Bend test (16 gauge mild gauge	Ball test (30 lb impact force inch lb)
4-84	40^+	0.93	no failure	no failure
4-85	40^+	0.94	" "	" "
4-86	45^+	0.92	" "	" "

B. PRIME COATED FILMS

Experiment number	Rubs (MEK)	Thickness (mm)	Bend test (16 gauge mild gauge)	Ball test (30 lb impact force inch lb)
1-1	5	0.16	no failure	no failure
1-2	7	0.13	" "	" "
1-3	20+	0.14	slight failure	slight failure
1-4	20+	0.20	no failure	" "
1-5	30+	0.19	" "	no failure
1-6	30+	0.11	" "	" "
1-7	40+	0.20	" "	" "