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EFFECT OF POWDER COMPACTION VARIABLES ON THE PERFORMANCE OF A PYROTECHNIC IGNITER*

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ABSTRACT

The compaction of the pyrotechnic powder against a bridgewire in an igniter is very critical to performance. The density of the compact at the bridgewire interface can be effected by the powder characteristics, environment, surface finish and configuration of the compact holder and the loading process. Some of these parameters have been evaluated and the effect determined on the bridgewire-powder interface as well as the initiation performance.

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EFFECT OF POWDER COMPACTION VARIABLES ON THE PERFORMANCE OF A PYROTECHNIC IGNITER

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INTRODUCTION

The premise that a uniform powder density will result from using a fixed applied pressure to load a pyrotechnic mixture into an igniter can be undermined by several physical factors. The compaction characteristics of a pyrotechnic powder are not only a function of materials but also the cavity configuration into which it is placed, the environment, and the processing conditions. All of these factors can influence the density gradient in the compact and thus, the density at the bridgewire. Since the density of the pyrotechnic around the initiating bridgewire is a critical parameter that affects the ignition of the pyrotechnic, these compaction parameters must be considered for any component design and fabrication process. This study evaluates some of these factors and the effect on performance.

Techniques were developed to estimate the density of the pyrotechnic at the bridgewire interface of an igniter. Parameters affecting the density at the bridgewire were then incorporated in the design and processing of inexpensive test components. The hot wire ignition performance of these components was determined and related to nondestructive test data and the estimated density.

DENSITY DETERMINATION

A method to estimate the density of the pyrotechnic at the bridgewire was developed. The method is a two-step process: first, measure the density of a thin compact (thin enough so that there is essentially no density gradient) as a function of applied pressure; and second, measure the pressure applied and transmitted during compaction in a configuration identical to an igniter design. The transmitted pressure data are then used to estimate the density at the bottom of the compact (relates to the density at the bridgewire in an igniter) using the pressure-density relationship established in the first step.

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The system used to obtain the pressure applied and the pressure transmitted is a commercial servo-hydraulic unit (manufactured by Materials Test System, Inc.) coupled with load cells and a displacement monitor. Load and displacement data are obtained by means of an X-Y recorder; the system is shown schematically in Figure 1. A sketch of the tooling is shown in Figure 2.

The charge holder used to obtain the pressure-density relationship was a smooth steel cylinder having an inside diameter of 4.29 mm and a length of 0.50 mm. At this length-to-diameter ratio (0.12), the pressure applied and transmitted during compaction was essentially equal indicating a uniform compact density. The cylinder was tare weighed, loaded with 15 mg of pyrotechnic powder, the loaded cylinder gross weighed, and the length of the compact measured. From these data, the density was calculated; this process was repeated at various applied pressures.

A pressure-density relationship was determined in this method for a 33/67% blend of titanium subhydride ($TiH_{0.65}$) and potassium perchlorate ($KClO_4$). This pyrotechnic is a very safe static-insensitive material which exhibits good ignition performance [1]. The pressure-density relationship was determined to be as follows:

$$P = 1.351\ \rho^{0.108}, \tag{1}$$

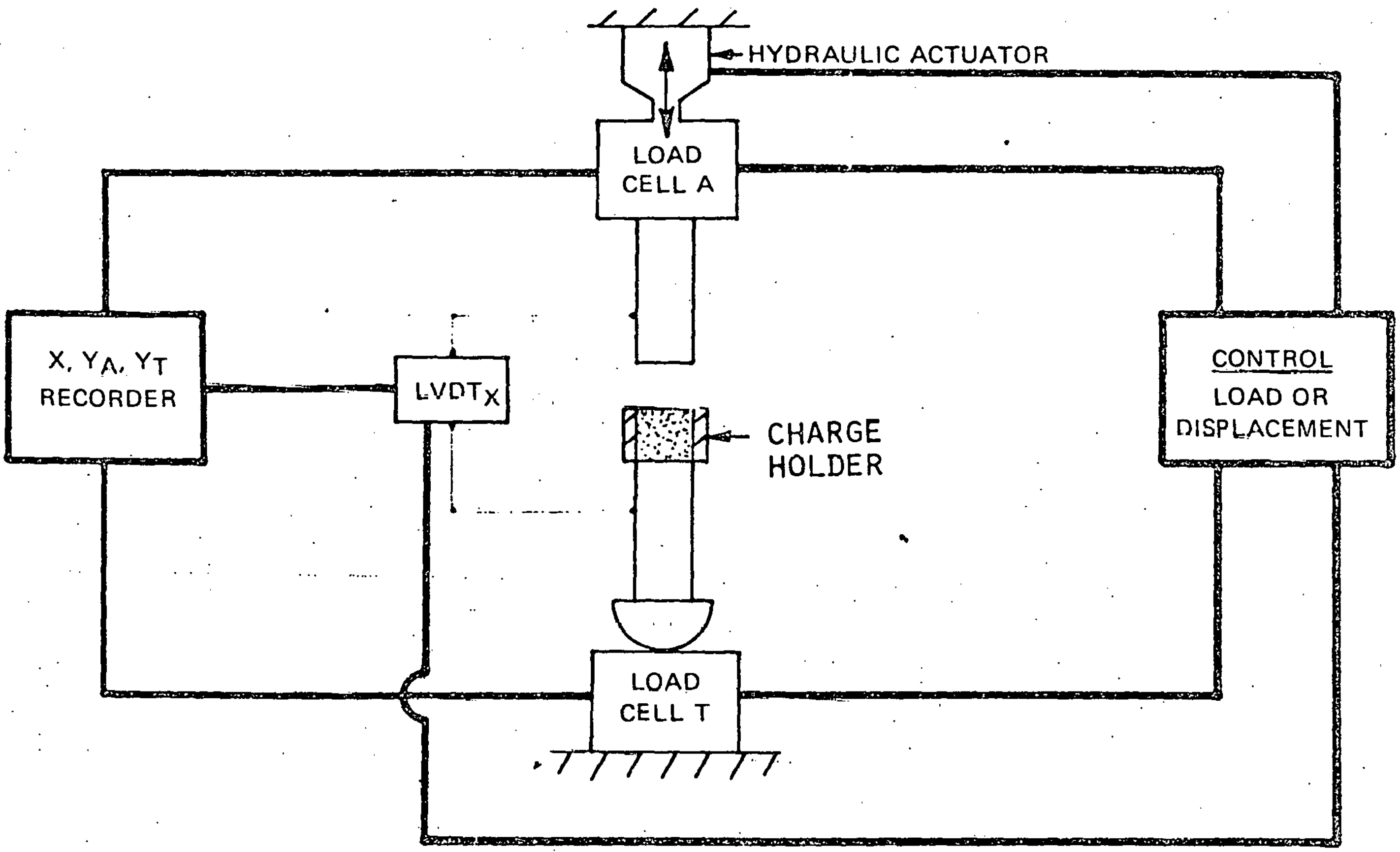

FIGURE 1 - Compaction test system.

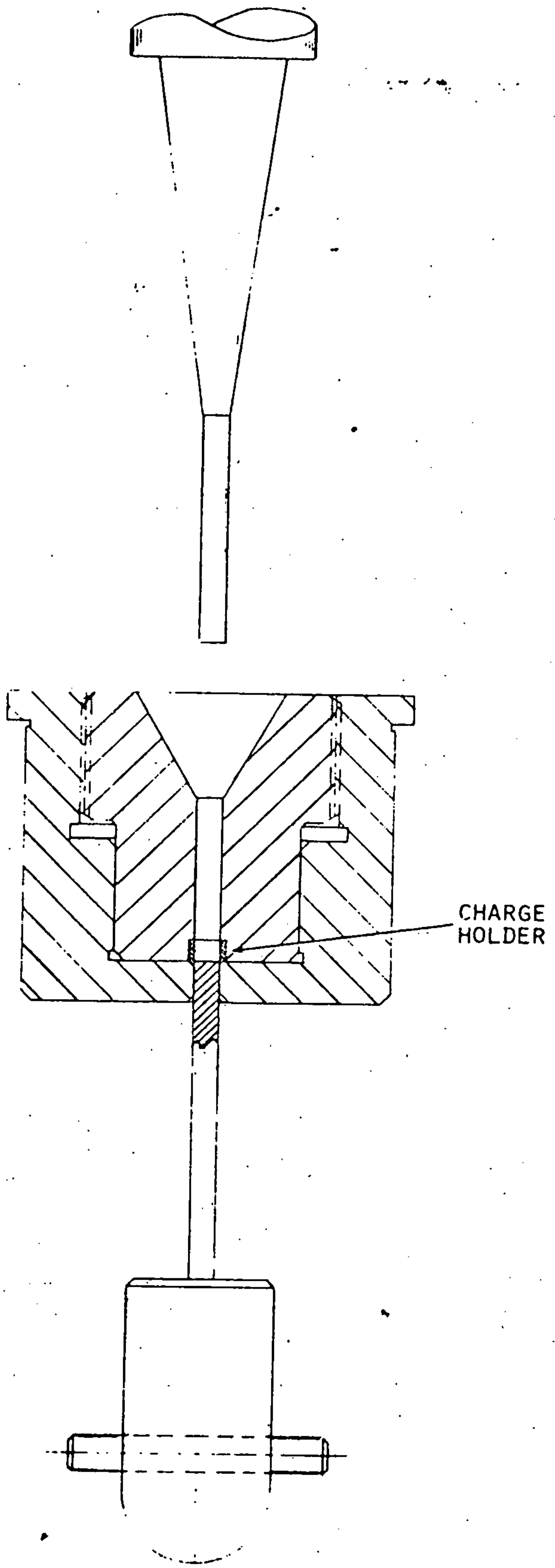

FIGURE 2 - Compaction test system tooling.

where:

P = pressure in MPa.
ρ = density in Mg/m^3.

This relationship is shown in Figure 3.

In order to estimate the density at the bridgewire of an igniter, the same test system was used. A charge holder, identical to the one in igniters, was used and subsequently tested. The cylinders had a 4.29 mm inside diameter and a length of 3.73 mm. Typical data acquired for a powder charge of 112 mg are shown in Figure 4. The force applied (F_a) and the force transmitted (F_t) are recorded as functions of displacement (compacted powder length). For these data, the pressure applied (P_a) and the pressure transmitted (P_t) can be related to the pressures during compaction of the pyrotechnic in an igniter component. The P_t can then be used to estimate the density at the bridgewire using the relationship developed in Eq. 1.

COMPACTION PARAMETERS

Three compaction parameters were evaluated: surface finish of the charge holder, powder storage humidity, and dwell time of the compaction pressure. The density of the powder at the bridgewire interface was estimated when dry pyrotechnic was compacted at 68.9 MPa into charge holders that had various surface finishes ranging from smooth (RMS <0.2 μm), to very rough (RMS >3.2 μm) and when pyrotechnic powder conditioned at 100% relative humidity for 36 hr was compacted at 68.9 MPa with smooth charge holders. These data are shown in Table 1. In addition, powder was compacted similarly at the pressure required to achieve a density of 1.89 Mg/m^3 at the bridgewire. These data are shown in Table 2.

The density at the bridgewire is 6.3% greater for the very smooth charge holder (Group A) when compared to the average charge holder (Group B). There was no difference in the average charge holder and the very routh charge holder (Group C). This is probably because the grooves in the average charge holder are larger than the particle size of the pyrotechnic. As a result, the frictional force for both the charge holders is the sliding friction of the powder against powder entrapped at the charge holder surface.

The density at the bridgewire is only 3.2% greater for the very smooth charge holders when the powder is treated at 100% relative humidity.

As shown in Table 2, 30-40% less applied pressure is required to load the very smooth charge holders and achieve the same density at the bridgewire as that obtained with 68.9 MPa in the rough charge holders.

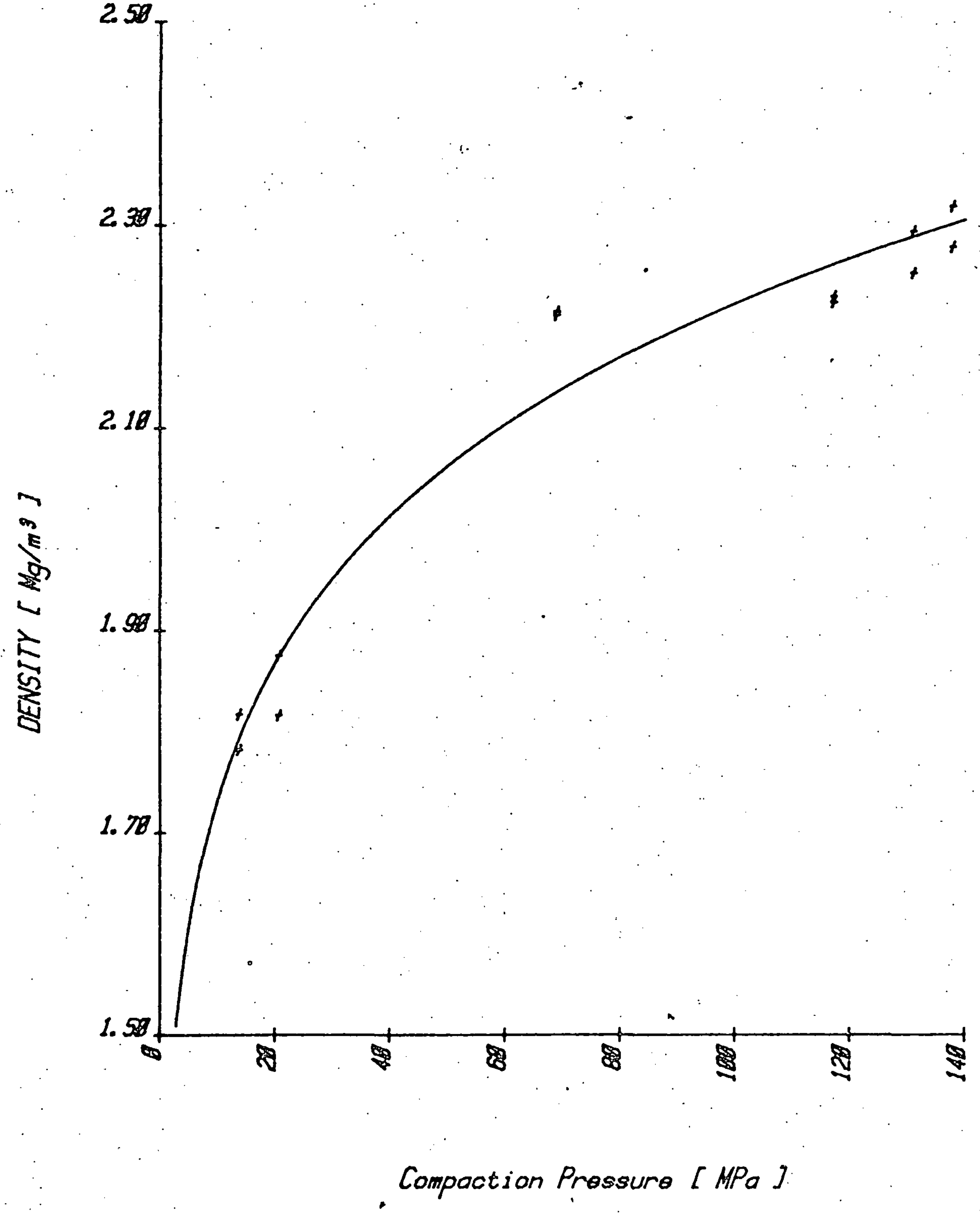
2.50
2.30
2.10
1.90
1.70
1.50
DENSITY [Mg/m³]
0
20
40
60
80
100
120
140
Compaction Pressure [MPa]

Fig 3

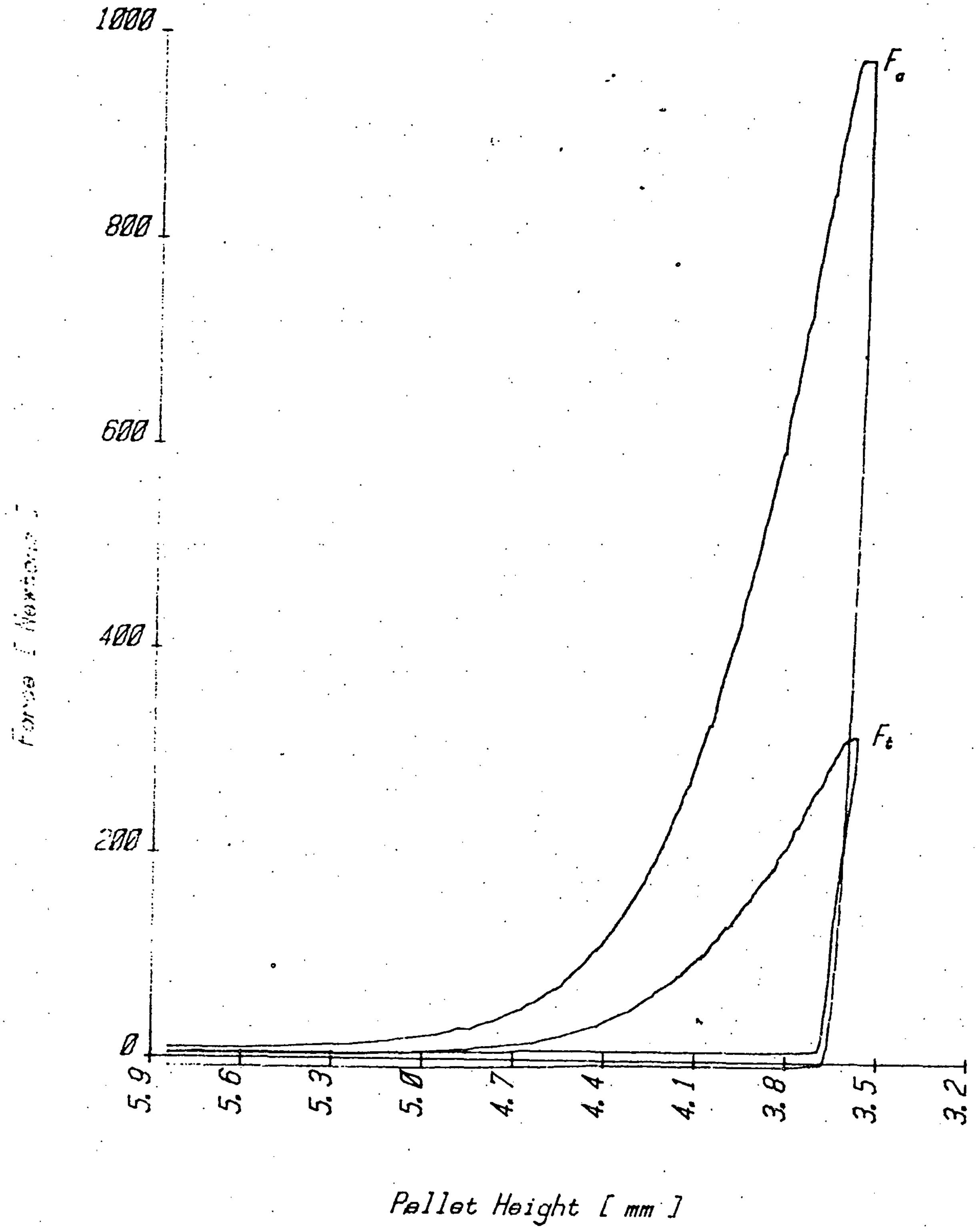
1000
800
600
400
200
Ø
Force [Newtons]
F_a
F_t
5.9
5.6
5.3
5.Ø
4.7
4.4
4.1
3.8
3.5
3.2
Pellet Height [mm]

Fig 4

Table 1

TRANSMITTED PRESSURE AND DENSITY WITH A CONSTANT APPLIED PRESSURE[a]

Group	Charge Holder Surface Finish (μm)	Powder Condition[b]	P_t (MPa)	P_t/P_a (%)	Average Density (Mg/m^3)	Density Estimate at Bridgewire (Mg/m^3)
A	<0.2	Dry	39.0	56.6	2.10	2.01
B	0.8 - 1.6	Dry	21.9	31.8	2.04	1.89
C	>3.2	Dry	21.5	31.2	2.05	1.88
D	<0.2	Wet	30.3	44.0	2.02	1.95

[a] 68.9 MPa

[b] Dry indicates powder stored in desiccator; wet indicates powder stored at 100% relative humidity for 36 hr.

Table 2

APPLIED PRESSURE REQUIRED TO ACHIEVE CONSTANT DENSITY AT BRIDGEWIRE[a]

Group	Charge Holder Surface Finish (μm)	Powder Condition[b]	P_t (MPa)	P_t/P_a (%)	Average Density (Mg/m^3)	Density Estimate at Bridgewire (Mg/m^3)
E	<0.2	Dry	42.6	51.2	1.98	1.89
B	0.8 - 1.6	Dry	68.9	31.6	2.04	1.89
F	<0.2	Wet	48.1	45.3	1.94	1.88

[a] P_t - 21.8 MPa

[b] Dry indicates powder stored in desiccator; wet indicates powder stored at 100% relative humidity for 36 hr.

BRIDGEWIRE PERFORMANCE

An inexpensive test device (MAD-1031), which is shown in Figure 5, was developed that simulates igniters used in special applications. The charge holder used in the MAD-1031 was identical to that used in previous density evaluation experiments. MAD-1031 components were fabricated with smooth and rough charge holders, with dry and moisture-treated powder, and with two different compaction dwell times.

Two significant parameters were measured on these components, that is, electrothermal response (ETR) gamma* and time-to-bridge burnout (BOT)** upon application of 3.5 A. These data, along with the estimated density at the bridgewire, are shown in Table 3.

A review of the data in Table 3 reveals a significant fact. Compacting powder at a constant pressure does not necessarily result in a constant density and therefore does not result in a constant ignition time--also, the higher the density--the higher the ETR gamma. This is expected; since, at the higher density, there is a greater heat loss to the powder while the bridge temperature is rising because of the application of an ETR current pulse (500 mA for 75 msec). Similarly, there is a greater heat loss to the powder during application of the firing pulse (3.5 A) resulting in longer ignition times.

The relationship between the BOT and the density at the bridgewire is shown in Figure 6. Note that at the density of 1.88-1.89 Mg/m^3, two groups were compacted at 68.9 MPa whereas two groups were compacted at 30-40% less pressure.

The relationship between the ETR gamma and the density at the bridgewire is shown in Figure 7. Although this correlation is not as good as the ignition time--density relationship, this nondestructive technique can be used as a guide to determine or achieve the desired density at the bridgewire. Figure 8 shows the relationship between the ignition time and the ETR gamma. This relationship also indicates that ETR gamma can be used as a guide to ignition performance.

*The ETR test was first proposed by Rosenthal and Minichelli [2] and further developed by Strasberg [3,4]. Gamma is the most useful parameter determined in the ETR test and is related to the rate of heat loss from the bridgewire.

**For these components, the time-to-bridge burnout and the ignition time of the pyrotechnic are indistinguishable.

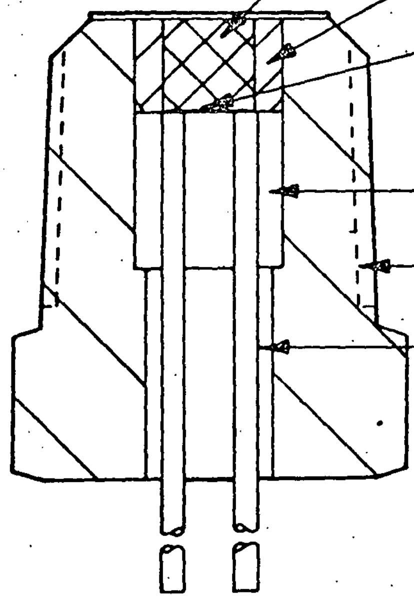

FIGURE 5 - MAD-1031 test component.

Table 3

ETR GAMMA AND TIME TO BRIDGE BURNOUT AS FUNCTION OF DENSITY AT BRIDGEWIRE

Group	Charge Holder Surface Finish (μm)	Powder Condition	P_a (MPa)	Density Estimate at Bridgewire (Mg/m^3)	Gamma (mW/°K)	BOT (msec)
A	<0.2	Dry	68.9	2.01	3.92	2.50
B	0.8 - 1.6	Dry	68.9	1.89	2.58	1.76
C	>3.2	Dry	68.9	1.88	2.97	1.79
D	<0.2	Wet	68.9	1.95	2.87	1.88
E	<0.2	Dry	42.6	1.89	2.28	1.77
F	<0.2	Wet	48.1	1.88	2.28	1.82
G[a]	<0.2	Dry	68.9	2.00	3.68	2.23

[a]Compaction pressure applied for 10 sec for Group G; compaction pressure applied for 30 sec in all other groups.

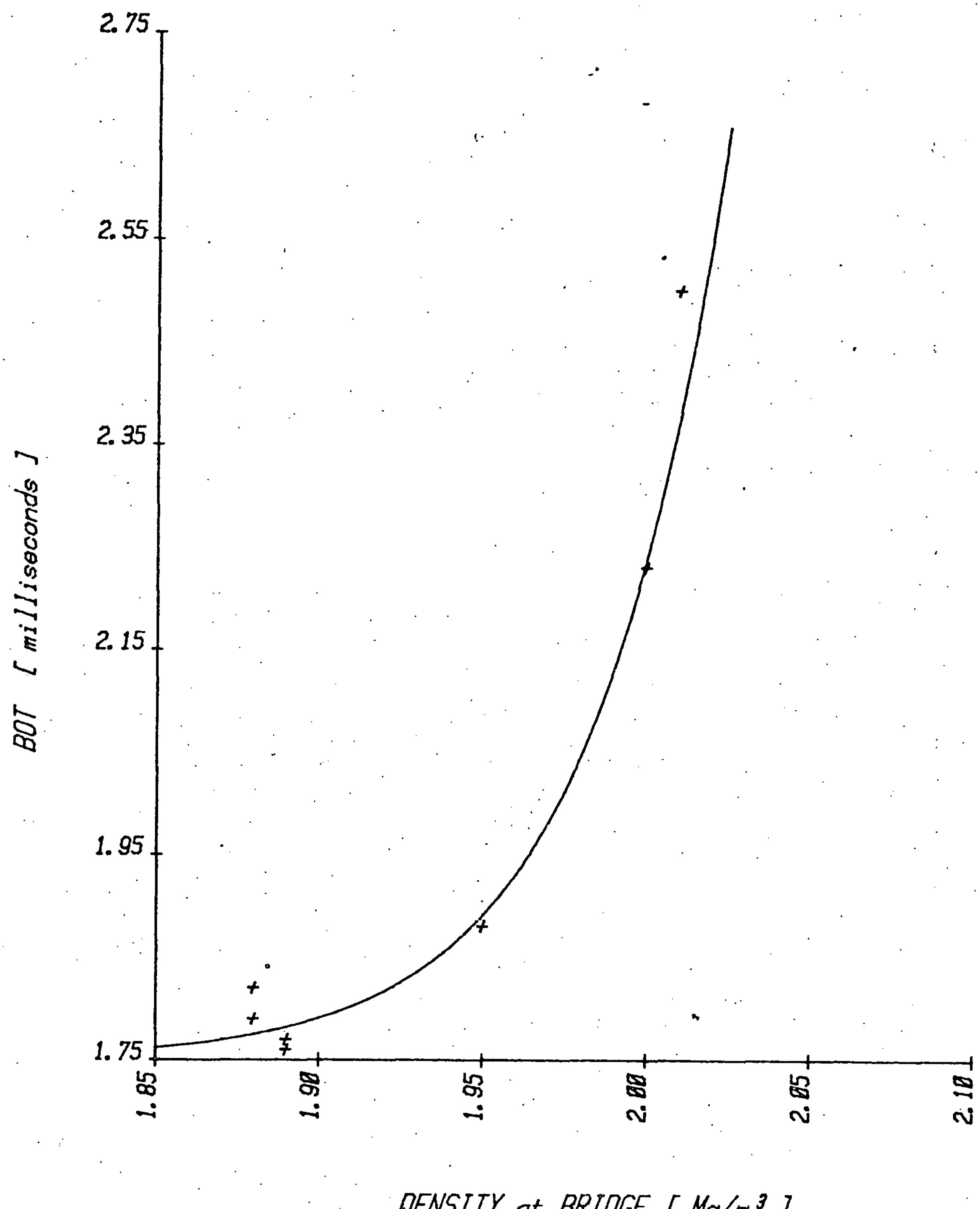
2.75
2.55
2.35
2.15
1.95
1.75
BOT [milliseconds]
1.85
1.90
1.95
2.00
2.05
2.10
DENSITY at BRIDGE [Mg/m 3]

Fig 6

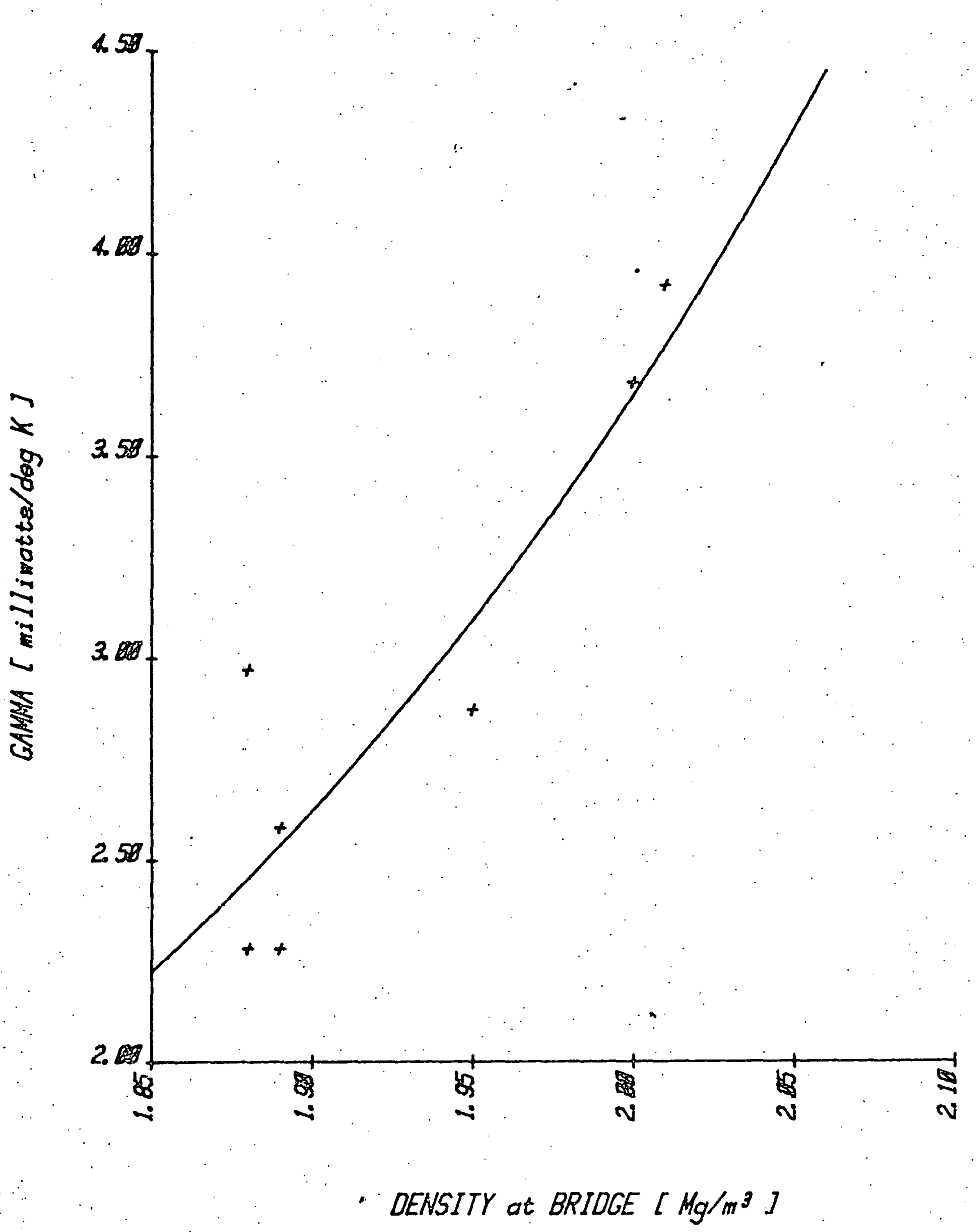
GAMMA [milliwatts/deg K]
4.50
4.00
3.50
3.00
2.50
2.00
1.85
1.90
1.95
2.00
2.05
2.10
DENSITY at BRIDGE [Mg/m³]

Fig 7

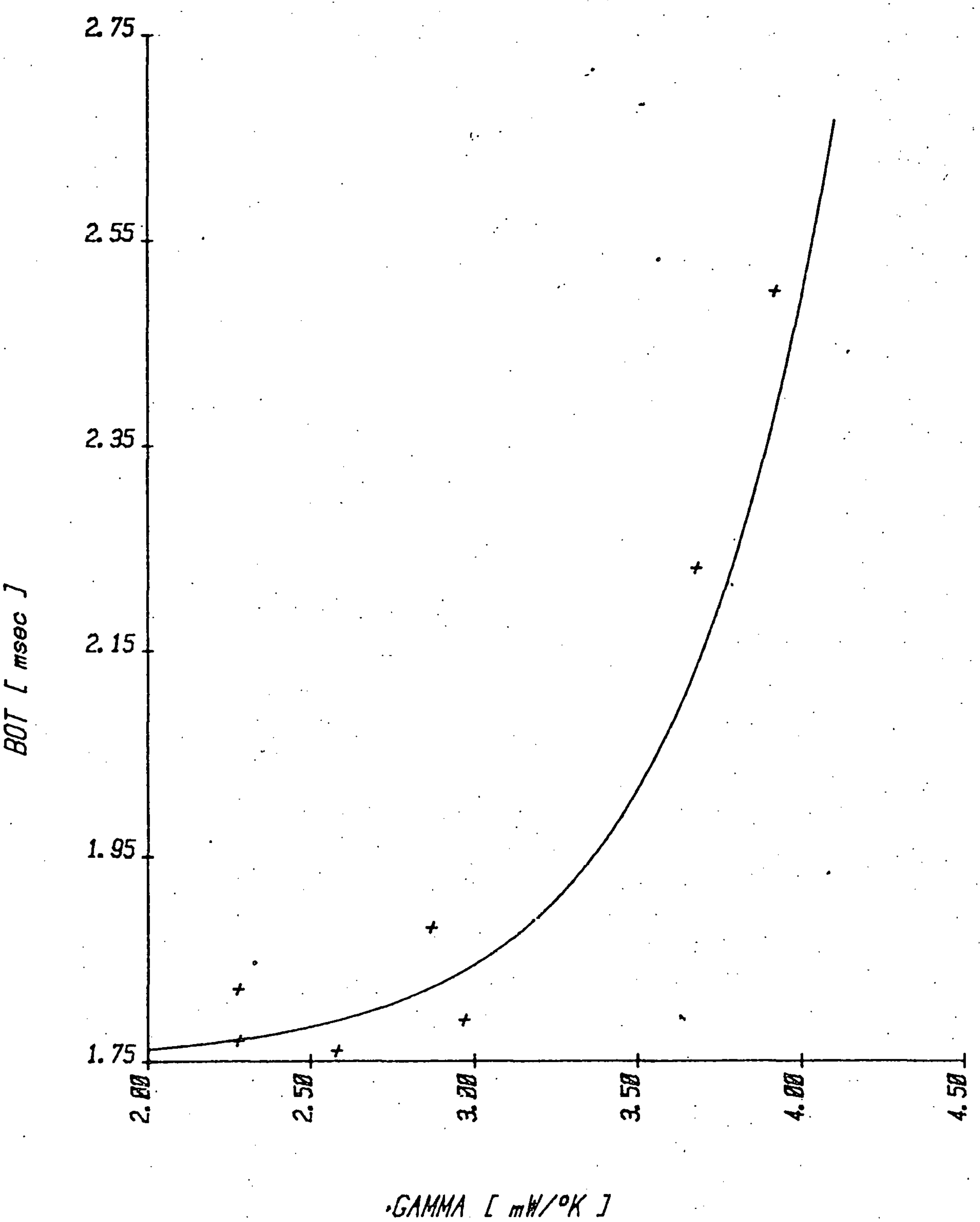
2.75
2.55
2.35
2.15
1.95
1.75
BOT [msec]
2.00
2.50
3.00
3.50
4.00
4.50
GAMMA [mW/°K]

Fig 8

SUMMARY AND CONCLUSIONS

A method to estimate the density of a pyrotechnic at the bridgewire interface was developed. This technique showed that, even though a constant compaction pressure was applied, the surface finish of the charge holder, the humidity of the environment in which the pyrotechnic was stored, and the time the compaction pressure was maintained on the powder, all had an effect on the density at the bridgewire. This effect can be detected by the nondestructive ETR test.

The destructive testing showed that the ignition time is a function of the density at the bridgewire and not the average density or the compaction pressure.

Manufacture of pyrotechnic igniters is commonly performed using a constant compaction pressure to control the process. This study shows that care must be exercised in the design of the component and in the control of process parameters that can affect the density gradient in the component.

One method to eliminate some of this problem is to reduce the length-to-diameter ratio of the compact (L/D was 0.87 for this work) to a value where the density gradient is minimized. However, this would result in the need for multiple loadings to fill the charge cavity and the subsequent cost of those loadings balanced against the cost of controlling the necessary process parameters.

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