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THE EFFECT OF CHARGE MIXTURE RATIO AND PARTICLE SIZE ON IGNITER PLUME HEAT TRANSFER CHARACTERISTICS

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SUMMARY

Investigation of the heat transfer characteristics of igniter output plumes, first reported at the Fourteenth International Pyrotechnics Seminar in 1989, has continued, using two types of igniter to determine the effect of charge mixture ratio and fuel particle size on performance. While both of these igniters had the same metallic closure disc (scored Hastelloy with a capture cone), the bridgewire sensitizer (or ignition mixture) was barium styphnate for one type, and a particular blend of fine particle titanium/potassium perchlorate ("PB") for the other type. The output mixture for both types was titanium/potassium perchlorate; two mixture ratios (33/67 and 41/59), and two titanium particle sizes (2 and 8 μm) were used. The results show that, for both types of igniter, the coarse particle size titanium produced the best performance. The overall best performance was obtained from the igniter using the "PB" ignition mixture and an output charge of 41/59 titanium/potassium perchlorate.

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INTRODUCTION

At the Fourteenth International Pyrotechnics Seminar, a new method was described (Ref. 1) for evaluating the capability of a small igniter to ignite its associated next-assembly. The method consisted principally of measuring the wall temperature with time when the igniter was fired into a closed bore hole representative of the center hole in a thermal battery. The temperature measurements were made with commercially available, fast response (10 μsec), sheathed chromel-constantan thermocouples, and allowed calculation of local wall heat transfer rates.

Since reporting the work in Ref. 1, it has been demonstrated that the igniter plume products deposited on the surface of the thermocouples, flush-mounted with the bore hole wall, seriously degrade the accuracy of the raw temperature-versus-time data. Consequently, the most accurate information is obtained as time $t \rightarrow 0$, before the build-up of plume products, and this particular time corresponds approximately with the generation of the maximum heat transfer rate into the bore hole wall. While the complete heat transfer process requires up to 20 msec, the local maximum of the wall temperature rise typically occurs within approximately 3 msec, and for convenience, igniter performance comparison has been based principally on this quantity.

The objective of the current series of tests was to determine of the effect of titanium/potassium perchlorate mixture ratio and titanium particle size on the potential capability of an igniter to ignite its next-assembly. Two types of igniter were investigated, with the principal difference being that one type, A, used barium styphnate as a bridgewire sensitizer, whereas the other Type, B, used titanium/potassium perchlorate in the ratio 33/67 with fine (2 μm) titanium particles.

In an actual application, the wall temperature rise achieved is a direct indication of the capability of an igniter to ignite its associated next assembly, and will clearly include the deleterious effects of the deposition of plume products during the time interval between igniter firing and ignition of the next assembly. However, in view of the increasing degradation in the accuracy of the thermocouple signal with time to indicate the temperature of a clean wall, integration of the heat transfer rate (typically to a time of the order of 20 msec from igniter firing) to estimate the wall heat flow has not been pursued.

APPARATUS

The apparatus (the same as used in Ref. 1) was relatively simple, consisting principally of a short section of a hexagonal stainless steel cylinder with the dimensions shown in Fig 1. A 3.18 mm diameter hole, 5.08 cm long, was accurately bored along the axis of the cylinder, and provision was made at one end of the bore to mount the igniter of interest in a leak-tight manner, using a thin (50 μm) copper gasket, while the other end was closed with a sealing plug containing an O-ring.

The fast-response thermocouples had the special construction shown in Fig 1. The stem is 3.18 mm diameter stainless steel (the same material as the test block), and the sensing element was made of very thin ribbons of chromel and constantan separated by a thin ribbon of mica, which was also used to insulate each element from the stainless steel body. The chromel-constantan thermocouple junction was made through abrasion welding by lightly drawing a medium grain sandpaper or a fine cut 3 mm diameter file perpendicularly across the ribbons. This action formed numerous "finger" junctions, with a response time that decreased to a limit of the order of 10 μsec as the fineness of the sandpaper or file increased. The junctions were readily checked for continuity by measurement of their thermoelectric output and their resistance. In practice, the junctions were quite rugged considering the especially harsh environment to which they were subjected.

Thermocouples were located at three stations along the bore length as shown in Fig 1. To provide smooth conformity with the bore, each thermocouple end was ground to a radius of 1.59 mm so that the ribbon thermocouple junction was exposed circumferentially. Gas-tight sealing was achieved with Swagelok-type nylon ferrules on the thermocouple stem. Each thermocouple was connected to a combined reference junction plus amplifier which was set at a calibrated gain of 10.

A separate port, as shown in Fig 1, was provided for measuring bore pressure with a PCB piezoelectric transducer with a nominal response of 500 KHz. The transducer port was located between a pair of thermocouple stations, and incorporated a mounting plug of polyetheretherketone (PEEK) to electrically isolate the transducer from the test block so that the electrical pulse to fire the igniter (with one grounded lead) would not produce interference on the pressure trace.

Data were recorded on three dual channel LeCroy 9400 digital oscilloscopes and stored in an IBM AT personal computer with full data reduction (described below), plotting and printing capability. One channel on each oscilloscope was used for recording pressure and triggering the second channel which recorded a thermocouple signal. In this way all three oscilloscopes were triggered simultaneously, and allowed the measurement of three thermocouple signals. Ports not occupied by thermocouples were filled with 3.18 mm-diameter stainless steel rods with the same end geometry as the thermocouples to provide smooth bore conformity.

TEST PROGRAM

The details of the two igniter types, A and B, that were investigated to determine the effect on performance of output mixture ratio and titanium particle size, are shown in Table 1. Titanium/potassium perchlorate is stoichiometric in the ratio 41/59 and oxidizer-rich in the ratio 33/67.

All igniters were fitted with capture cones and Hastelloy closure discs which were screened for best repeatability of score depth from piece to piece to eliminate, as far as possible, the effect of this parameter on the output plume thermal characteristics. (The effect of score depth is due to be investigated in a later series of tests.)

TABLE 1. CHARACTERISTICS OF TESTED CHARGES

Charge Number	Sensitizer	Output Charge (Particle Size)	Ratio	ΔH cal
A1	5.3 mg $BaC_6H_3N_3O_9$	6.7 mg Ti(2μm)/$KClO_4$	33/67	10.9
A2	" "	6.7 mg Ti(8μm)/$KClO_4$	33/67	10.9
A3	" "	6.7 mg Ti(2μm)/$KClO_4$	41/59	13.3
A4	" "	6.7 mg Ti(8μm)/$KClO_4$	41/59	13.3
B1	5.0 mg Ti(2μm)/$KClO_4$	5.2 mg Ti(2μm)/$KClO_4$	33/67	13.5
B2	" "	5.2 mg Ti(8μm)/$KClO_4$	33/67	13.5
B3	" "	5.2 mg Ti(2μm)/$KClO_4$	41/59	16.2
B4	" "	5.2 mg Ti(8μm)/$KClO_4$	41/59	16.2

PROCEDURE

Before each test, the bore hole (with thermocouples removed) was carefully cleaned by gently scraping with a fine-cut circular file, blown through with an air jet, and then a snugly fitting cotton swab soaked in acetone was pulled through. Each thermocouple tip was burnished clean and replaced in the bore with smooth conformity and alignment, using a removable rod having a diameter that was approximately 0.05 mm less than the bore diameter.

A typical set of raw data traces for pressure and one thermocouple signal is shown in Fig 2. The pressure of interest was the peak value (4.70 MPa) produced by passage of the igniter output shock wave after rupture of the closure disc. The gradual pressure rise starting at approximately 10 msec was erroneous and due to heating beyond the temperature-compensated range of the instrument. The thermocouple trace indicated a peak temperature rise of 255°C above room temperature at the center of the bore length.

Assuming one dimensional heat flow in a semi-infinite solid with constant thermal properties, the local surface heat transfer rate is given by (Ref 2)

$$q_w(t) = \frac{k}{(\pi\alpha)^{1/2}} \int_0^t \frac{dT_w(\lambda)}{d\lambda} \frac{d\lambda}{(t-\lambda)^{1/2}} \qquad (1)$$

where
- k = solid thermal conductivity,
- α = solid thermal diffusivity,
- t = time, and
- $T_w(t)$ = surface temperature variation with time

For data reduction purposes, the finite difference form of Eq. 1 is

$$q_w(t_n) = \frac{2k}{(\pi\alpha)^{1/2}} \sum_{i=1}^{n} \frac{\Delta T_{wi}}{\Delta t_i} \left[\left(t_n - t_{i-1}\right)^{1/2} - \left(t_n - t_i\right)^{1/2} \right] .$$

At an oscilloscope sweep rate of 5 msec/division (Fig. 2), digital data points were stored every 12.4 μsec which was appropriately compatible with the thermocouple response of 10 μsec. Fifty data points (i.e., n = 50) covering a time interval of 0.62 msec were used to calculate successive values of $q_w(t_n)$, and 60 such values (to a final time t_f=37.2 msec) were used to construct the curve for q_w shown in Fig. 3. The acceptability of using the relatively simple planar heat flow equation (Eq. 1) for the current cylindrical geometry was established in Ref 1.

To account for the difference in calorific values of the various charges, the results to be presented for ΔT_w, q_w and the peak pressure, P_{max}, have been normalized by multiplying them by $\Delta H_o/\Delta H$, where ΔH_o = 13.5 cal and ΔH is given for each charge in Table 1. In this way, the results are scaled (as in Ref. 1) as though each charge had a calorific value of 13.5 cal., and provides a better basis of comparison.

RESULTS AND DISCUSSION

Starting at a room temperature of approximately 25°C, five tests were performed for each type of charge for igniters A and B (as shown in Table 1), and the average results for the maximum rise in wall temperature, $\overline{\Delta T}_{wmax}$, at the three locations along the bore for each igniter are shown in Fig. 4. The number at each plotted point is the standard deviation in that value of $\overline{\Delta T}_{wmax}$. For each charge configuration, $\overline{\Delta T}_{wmax}$ was lowest at the beginning of the bore, and increased steadily to the center of the bore. From the center of the bore to the end, charges containing barium styphnate produced values of $\overline{\Delta T}_{wmax}$ that generally increased faster than those containing the "PB" ignition mixture. With one exception, the values of $\overline{\Delta T}_{wmax}$ were highest at the end of the bore. This exception involved the charge, B4, with the highest value of $\overline{\Delta T}_{wmax}$ = 247°C (at the center of the bore), which then decreased by just 7°C at the end of the bore.

Figure 5 shows that the trend for the average maximum heat transfer rate $\overline{q}_{wmax}$, was approximately the same as for $\overline{\Delta T}_{wmax}$.

From the results in Figs. 4 and 5, the highest values of $\overline{\Delta T}_{wmax}$ and $\overline{q}_{wmax}$ for both types of igniter were obtained when using coarse particle (8 μm) titanium in the output charge. This effect was probably due to the fact that coarse titanium particles burn more slowly than fine particles. Hence, compared with fine particles, a larger proportion of the coarse particle energy release could occur in the bore volume. The highest overall value of $\overline{\Delta T}_{wmax}$ was achieved with a Type B igniter using an output mixture ratio of 41/59, whereas the highest value of $\overline{\Delta T}_{wmax}$ for a Type A igniter occurred with an output mixture ratio of 33/67.

In Fig. 6, the double bar quantities, $\overline{\overline{\Delta T}}_{wmax}$ and $\overline{\overline{q}}_{wmax}$ correspond to the average of each quantity along the bore length (3 locations) for the 5 tests of each charge mixture, requiring a total of 15 values averaged for each plotted point. It is seen that $\overline{\overline{\Delta T}}_{wmax}$ and $\overline{\overline{q}}_{wmax}$ followed essentially the same trend, with charge B4 again producing the best performance, but, the average peak pressure, $\overline{P}_{max}$, did not correlate with the two thermal results. The use of barium styphnate (a gas producer) as an ignition mixture increased the peak pressure compared with the use of the "PB" mixture. Also, regardless of titanium particle size, titanium/potassium perchlorate in the ratio 33/67 produced higher peak pressures than the ratio 41/59.

It is especially interesting to note that the overall best performing charge mixture, B4, also produced the overall lowest peak pressure. This could be a definite advantage in igniter design, since lower output pressures imply decreased damage potential in the next-assembly.

CONCLUSIONS

Wall temperatures produced by the output plumes of two different types of igniter, A and B, in a small diameter (3.18 mm), smoothly closed cylindrical bore hole were measured by fast response (10 μsec) chromel-constantan thermocouples. Igniter Type A contained barium styphnate as an ignition sensitizer, while Type B used a fine (2 μm) particle titanium/potassium perchlorate mixture ("PB") in the ratio 33/67. Both types of igniter used an output mixture of titanium/potassium perchlorate. Two titanium particles sizes (2 μm and 8 μm) and two output mixture ratios [33/67 and 41/59 (stoichiometric)] were investigated in all four combinations to determine their effect on igniter performance. The principal conclusions drawn were:

1. For both igniter types, the highest values of average maximum wall temperature increase, $\overline{\overline{\Delta T}}_{wmax}$, and average maximum wall heat transfer rate, $\overline{\overline{q}}_{wmax}$, were produced by coarse (8 μm) particle titanium.

2. The highest overall value of $\overline{\overline{\Delta T}}_{wmax}$, was achieved by the Type B igniter using the "PB" sensitizer mixture with an output mixture of 8 μm titanium/potassium perchlorate in the ratio 41/59. This performance occurred at the lowest peak pressure of any charge mixture.

3. The use of barium styphnate (a gas producer) as an ignition sensitizer increased the peak pressure compared with the "PB" mixture.

4. Regardless of titanium particle size, titanium/potassium perchlorate in the ratio 33/67 always produced higher peak pressures than the 41/59 ratio.

REFERENCES

1. Evans, N. A. and Durand, N. A.; Fourteenth International Pyrotechnics Seminar, "Heat Transfer Characteristics of Igniter Output Plumes; September 1989.

2. Nanigian, J.; Instruments and Control Systems, "Rocket Igniter Characteristics"; May 1967.

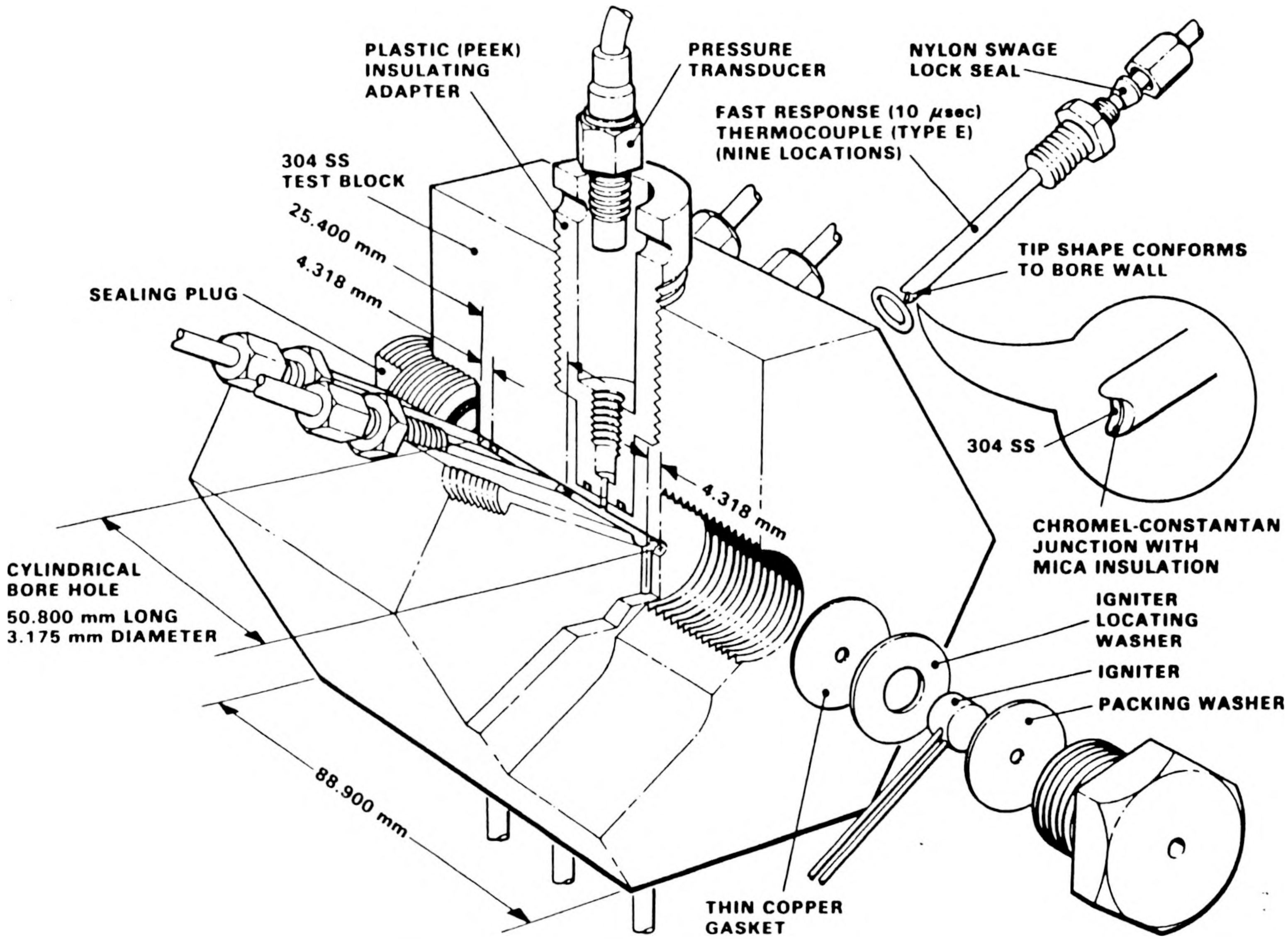

FIG. 1 Igniter Heat Transfer Apparatus

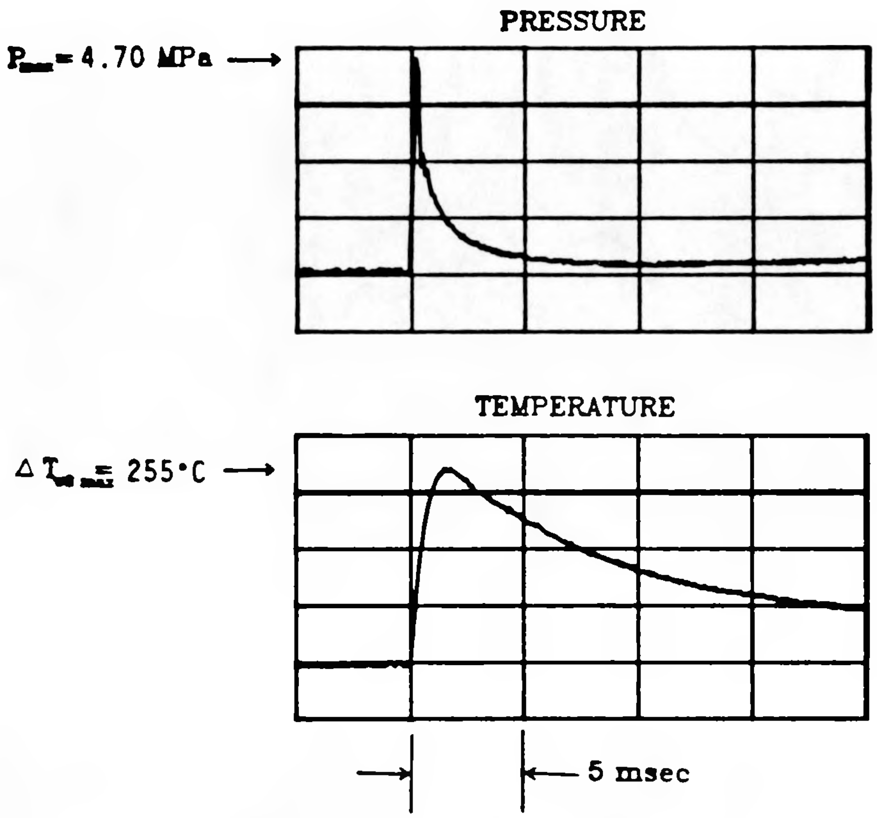

FIG. 2 Typical Raw Data Traces

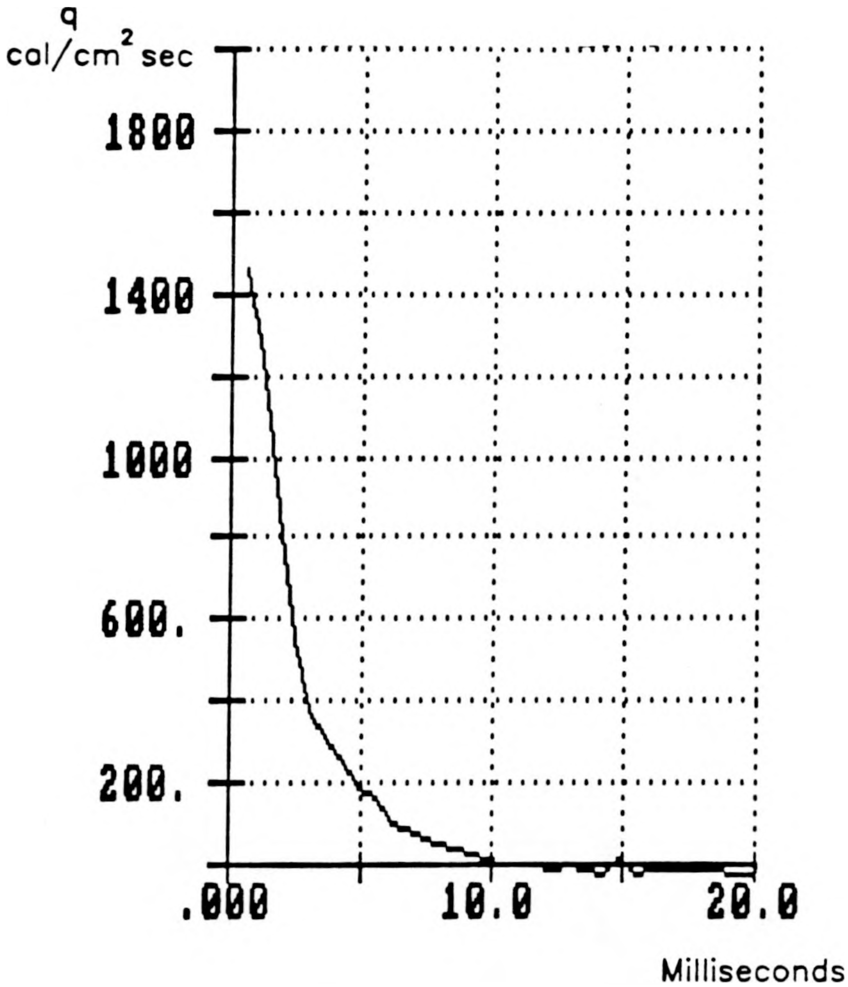

FIG. 3 Wall Heat Transfer Rate from Temperature Trace in Fig. 2

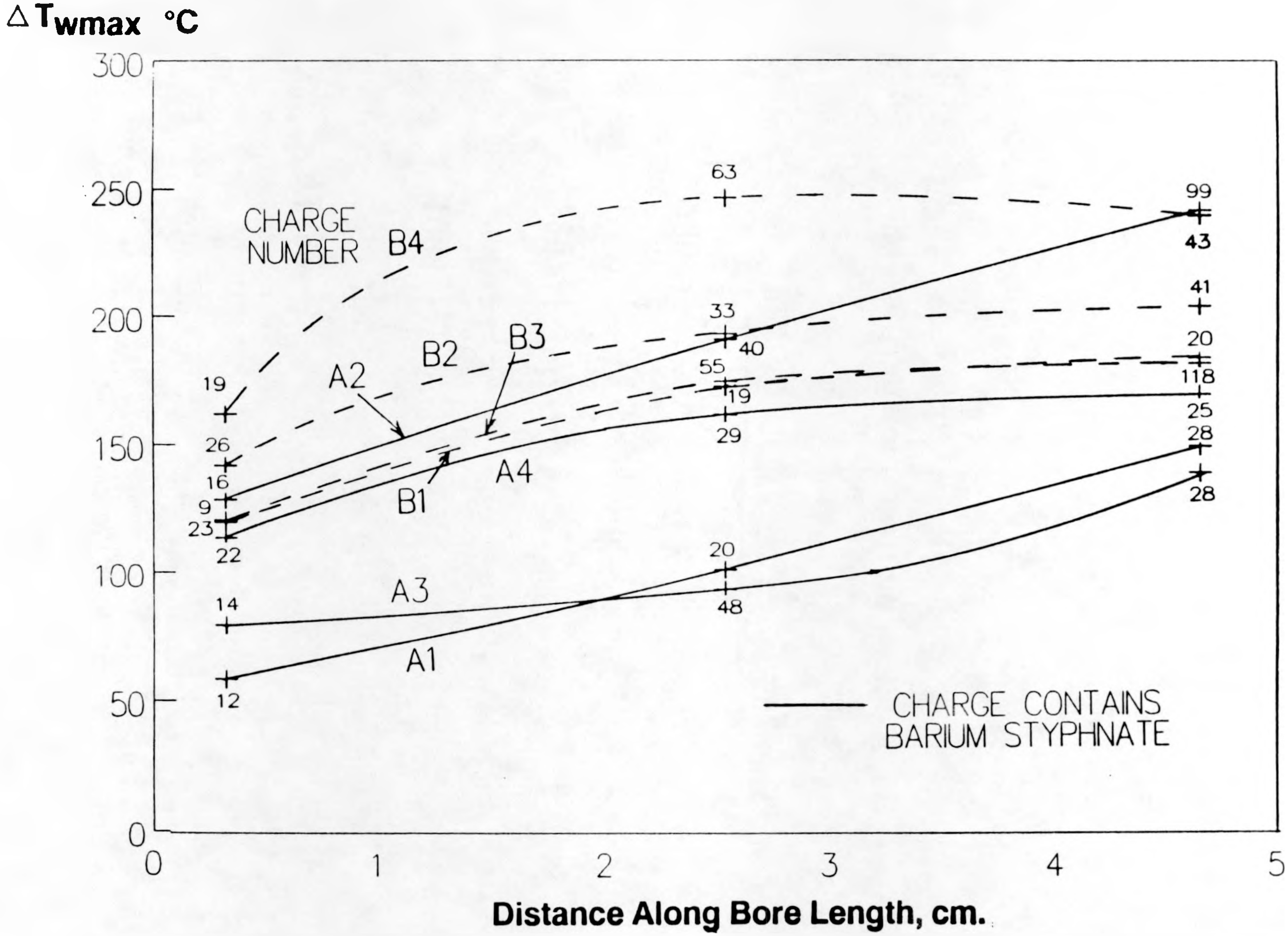

Fig. 4 Average Maximum Wall Temperature Increases Along Bore Length

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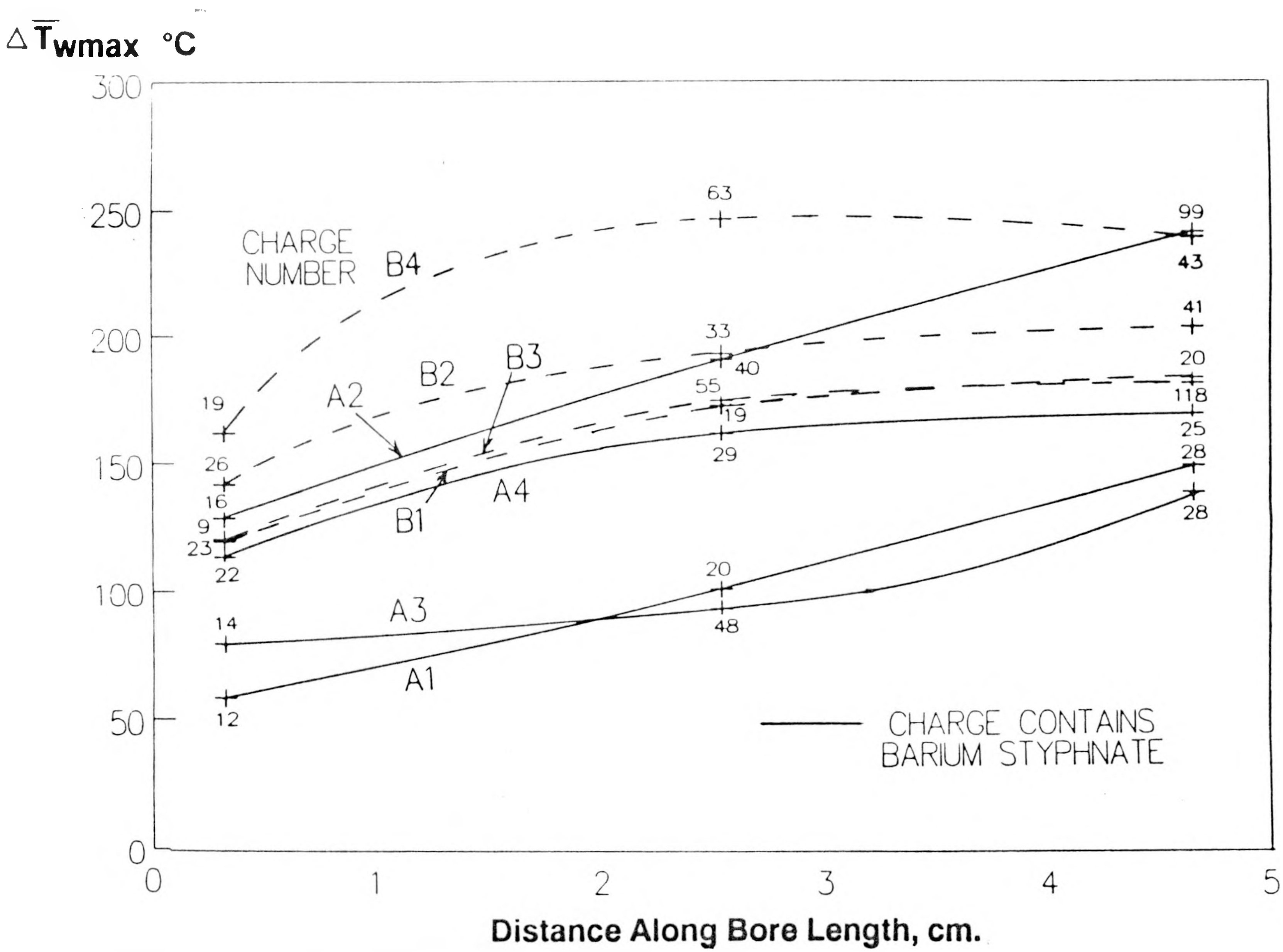

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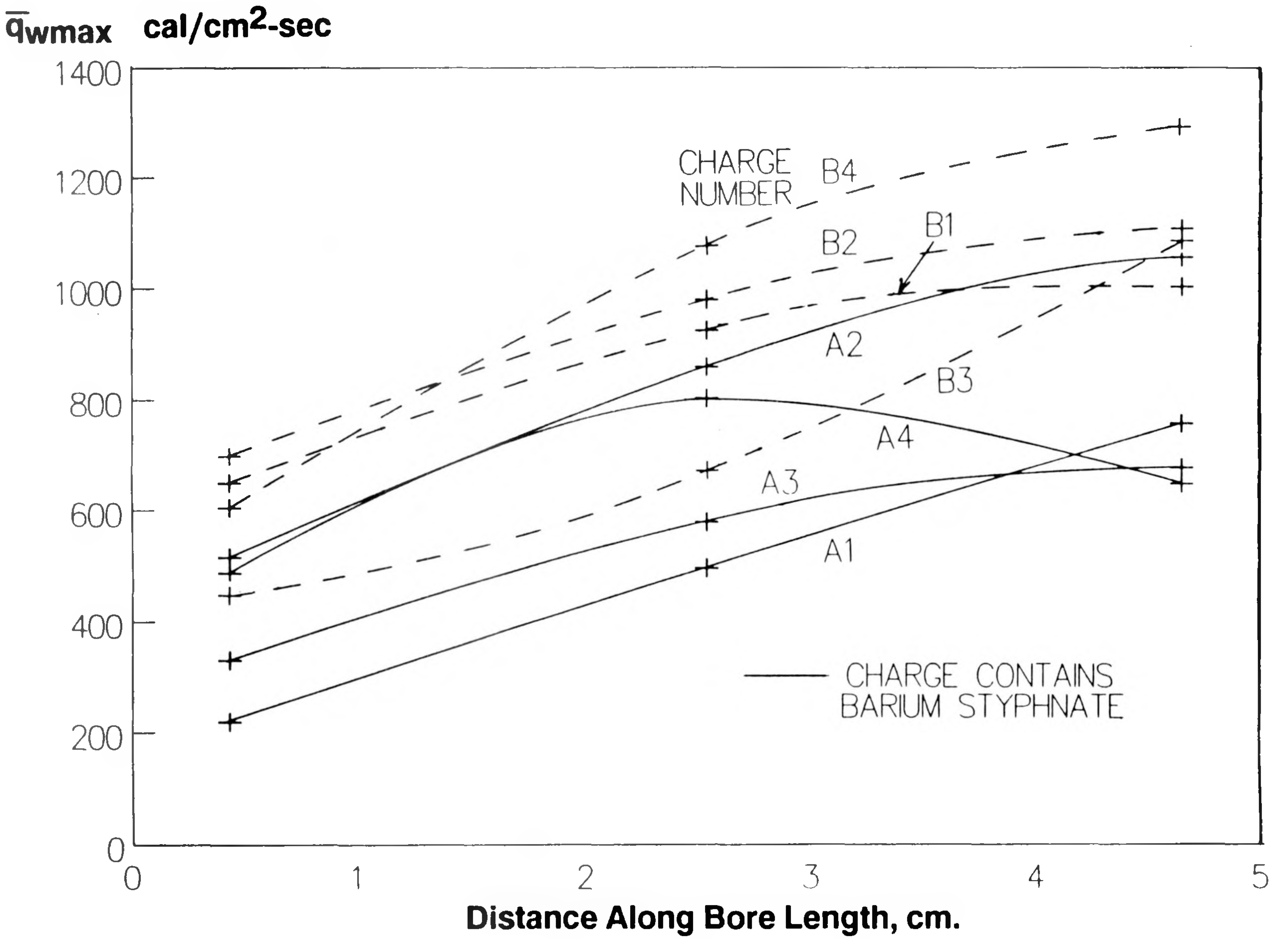

Fig. 5 Average Maximum Wall Heat Transfer Rates Along Bore Length

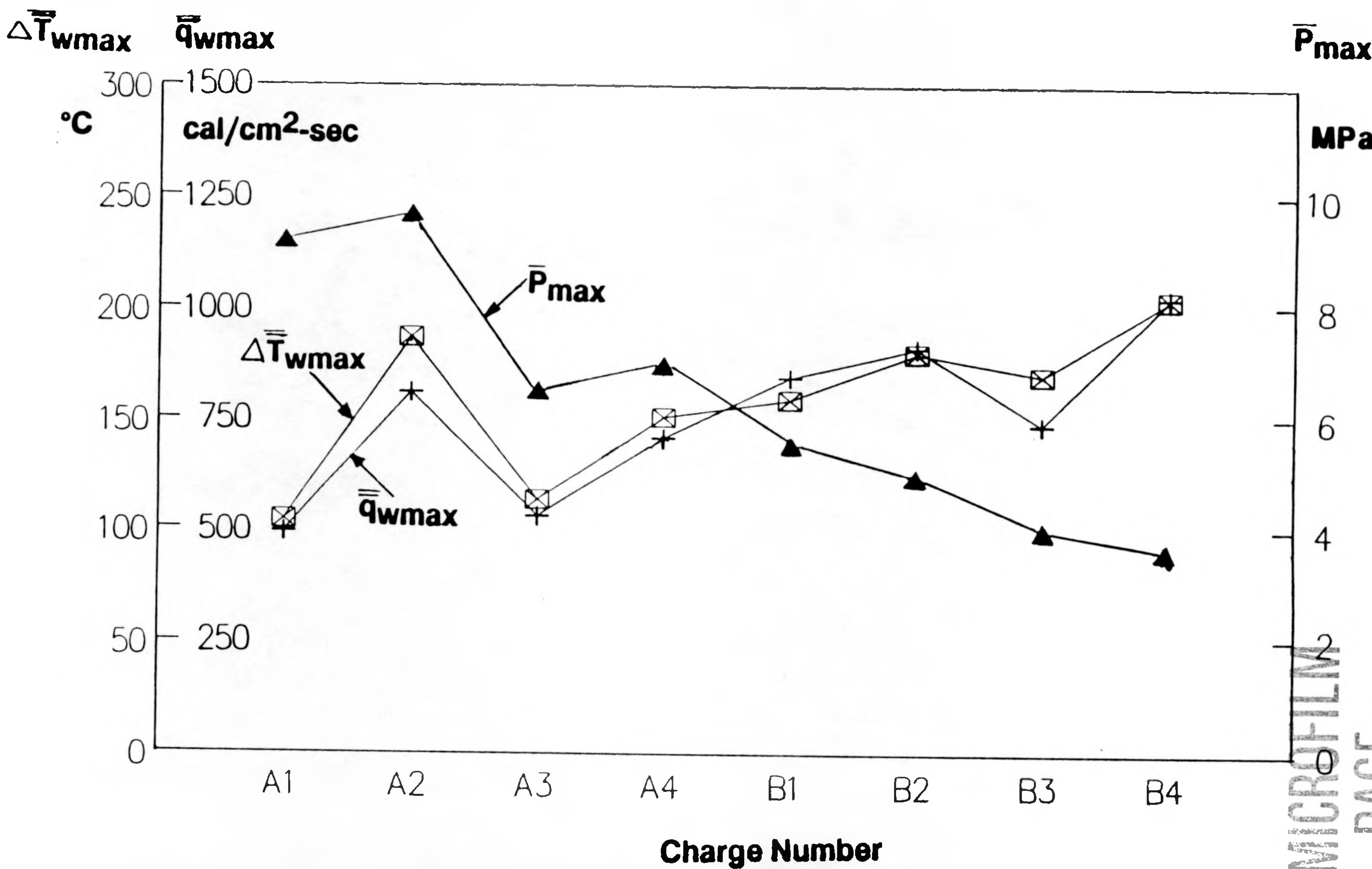

Fig. 6 Performance Comparison of the Various Types of Charge Mix

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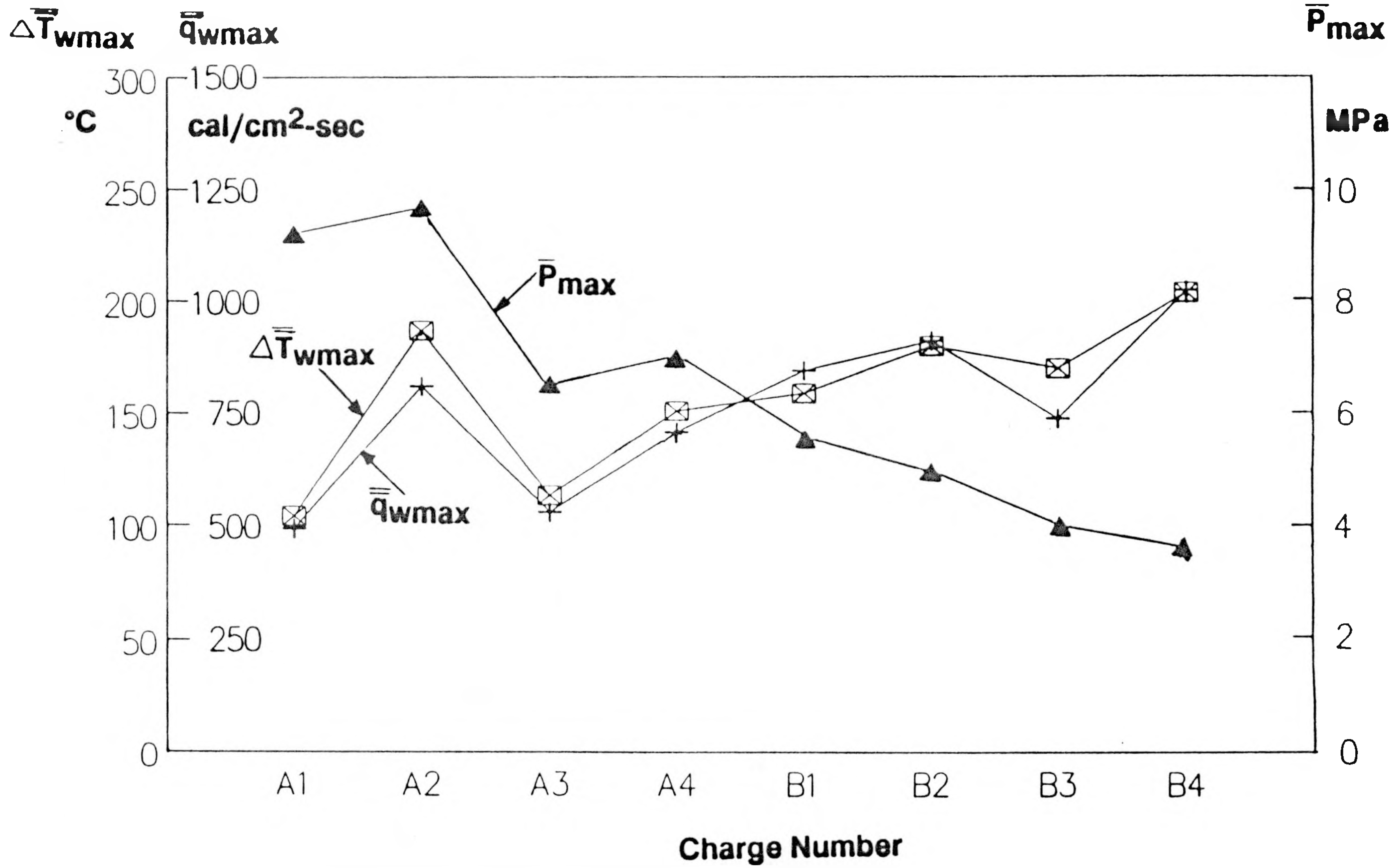

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