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INVESTIGATION OF THE REACTION OF ALUMINUM-LITHIUM ALLOY WITH WATER BY THE EXPLODING WIRE TECHNIQUE

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RESEARCH AND TECHNOLOGY DEPARTMENT

1 DECEMBER 1986

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19. ABSTRACT (Continue on reverse if necessary and identify by block number) The chemical reactivity of an aluminum-lithium alloy with water was studied by the exploding wire technique. The reactivity was measured by the amount of hydrogen gas product vs the dissipated energy (heat) through the alloy wire. The results show that a small concentration of Li (2.5 weight%) in the alloy has a profound effect on the reactivity. The amount of the dissipated energy through wire was controlled by using crowbar switch current interruptor. The higher reactivity of the alloy wire was observed in the following aspects: The alloy wire with an input energy of 4 kJ/gm, reacts with the water almost completely, whereas aluminum wire requires an input energy of 10 kJ/gm to complete the reaction. The alloy wire exploded at a lower temperature than aluminum wire provided that their initial heating rates were the same. The input energy that contributes to the chemical conversion of the wire material was supplied through heating during a very short time span, approximately 15 μ seconds for the alloy wire and 30 μ seconds for aluminum wire.					
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19. (Cont.)

The shorter time span of the alloy wire could indicate faster opening of the alloy wire probably due to more ready dispersion of the melt within water.

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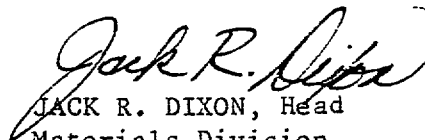
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FOREWORD

This report describes experimental work done to study the reaction of aluminum-lithium alloy melt with water. The aim of the work was to provide data as to the effect on the chemical reactivity of aluminum with water by the addition of a small amount of lithium. The results show that the chemical reactivity with water is greatly enhanced by the addition.

This work was supported by the NAVSEA 6.2 Block Explosive Program (L. A. Roslund), the NAVSEA 6.1 Explosive Program (H. G. Adolph) and the NSWC IR Program. The authors wish to express their appreciation to Hubert Hall for experimental assistance and to J. C. James and R. Jones for making sample wires.

Approved by:


JACK R. DIXON, Head
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CONTENTS

<u>Chapter</u>		<u>Page</u>
1	INTRODUCTION	1
2	BASICS OF ELECTRICAL AND CHEMICAL MEASUREMENTS	2
	ELECTRICAL MEASUREMENTS	2
	HYDROGEN MEASUREMENT	5
3	EXPERIMENTAL	9
	WIRE FABRICATION	9
	REACTION VESSEL AND HYDROGEN MEASUREMENT	9
	CURRENT PULSE GENERATION AND ELECTRICAL MEASUREMENTS	11
4	RESULTS AND DISCUSSION	13
	PHYSICAL PROPERTIES OF SAMPLE WIRES	13
	RESISTANCE CURVES	13
	REACTIVITY FROM HYDROGEN MEASUREMENTS	18
5	CONCLUSIONS AND FUTURE WORK	28

ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
1	EQUIVALENT CIRCUIT FOR CAPACITOR-DISCHARGE CIRCUIT	3
2	TYPICAL WAVEFORMS OF CURRENT, VOLTAGE, POWER, AND TOTAL DISSIPATED ENERGY FOR ELECTRICAL EXPLOSION OF ALUMINUM IN WATER	4
3	DETERMINATION OF GAS VOLUME(V) AFTER EXPLOSION. TOTAL GAS PRESSURE (P) REDUCES TO P' UPON OPENING OF THE VALVE THAT CONNECTS THE VESSEL TO A CALIBRATED VOLUME (V_1) UNDER VACUUM	6
4	REACTION VESSEL AND MEASUREMENT OF HYDROGEN GAS	10
5	SCHEMATIC ELECTRICAL SETUP FOR EXPLODING WIRE EXPERIMENTS	12
6	SEM PICTURES OF Al-Li AND Al WIRES	15
7	CURRENT AND VOLTAGE PROFILES OF EXPLODING WIRES FIRED AT DIFFERENT INITIAL BANK VOLTAGES. THE NUMBER ON EACH CURVE DENOTES INITIAL BANK VOLTAGE	16
8	RESISTANCE AND TOTAL DISSIPATED ENERGY PROFILES OF EXPLODING WIRES	17
9	FRACTION OF EXPLODING WIRES THAT UNDERWENT CHEMICAL REACTION WITH WATER AS A FUNCTION OF DISSIPATED ENERGY. THE ENERGY WAS CONTROLLED BY VARYING CAPACITOR BANK VOLTAGES	20
10	TYPICAL CURRENT, VOLTAGE, DISSIPATED ENERGY PROFILES OF EXPLODING WIRES FIRED AT A FIXED BANK VOLTAGE WITH DIFFERENT CURRENT INTERRUPTION TIME	22
11	FRACTION OF EXPLODING WIRES THAT UNDERWENT CHEMICAL REACTION AS A FUNCTION OF DISSIPATED ENERGY. THE ENERGY WAS CONTROLLED BY CURRENT INTERRUPTION METHOD	24
12	THE EXTENT OF CHEMICAL REACTION OF EXPLODING WIRES WITH WATER AS A FUNCTION OF THE DURATION OF DISCHARGE CURRENT	25

TABLES

<u>Table</u>		<u>Page</u>
1	PHYSICAL CONSTANTS OF ALUMINUM AND ALUMINUM-LITHIUM ALLOY	14
2	TOTAL DISSIPATED ENERGY AND CHEMICAL CONVERSION OF EXPLODING WIRES FIRED AT DIFFERENT BANK VOLTAGES	19
3	TOTAL DISSIPATED ENERGY AND CHEMICAL CONVERSION OF EXPLODING WIRES FIRED AT A FIXED BANK VOLTAGE WITH DIFFERENT CURRENT INTERRUPTION TIME	23

CHAPTER 1

INTRODUCTION

The reaction between molten metal and water can be explosive if thermal and chemical interactions are completed at a rapid rate. Mixing of molten aluminum with water can sometimes lead to vapor explosion without any chemical reaction between them. If, however, the mixing results in a chemical reaction, the aluminum-water system can outperform most conventional explosives by generating 3.6 kcal of energy and 1.4ℓ of hydrogen gas (per gram). However, the use of aluminum as a primary explosive, not as an additive to conventional formulations in, e. g. underwater munitions has been hampered by the difficulties of attaining the conditions needed to initiate and sustain an explosive reaction with water. The temperature of aluminum required to sustain its reaction with water is normally far above its melting point. The results of the study by Kubose et. al.¹, show that even shock heating is not an efficient way to raise the aluminum temperature unless some modifications are made on the material. Because of this extremity in the condition for the reaction, not many experimental techniques are available for the study of the system. The investigations in the past on molten metal-water system mainly dealt with steam explosions in which little chemical reaction takes place.²

In this investigation we attempted to find whether a metallurgical altering of aluminum would enhance its chemical reactivity with water thus providing a means to ease the aforementioned difficulties. The chemical reactivity was studied by means of the exploding wire technique. This technique was successfully applied to aluminum foil by Friedman et. al.³ Basically two parameters were controlled; the metallurgical composition of aluminum wire and the energy dissipated through wire as a form of Joule heat. The composition of aluminum was modified by adding a small amount of lithium (2.5 weight %).

The reactivity of the material with water was studied first by examining the electrical resistance of the exploding wires and then by measuring the hydrogen gas generated from the reaction. The dissipated energy through the wires, which gives a rough estimate of wire temperature, was controlled in the first series of the tests by adjusting capacitor bank voltage. In the later series of the tests, the energy was controlled in a more refined way by varying the duration of current flow.

The basic principles of electrical and chemical measurements employed in the investigation are explained in Chapter 2. Sample wire preparation and the details of the exploding wire experiments are described in Chapter 3. Test results, mainly in the forms of current-time and voltage-time profiles and volume of generated hydrogen gas, are presented in Chapter 4 along with the discussions of the results. Hydrogen measurements by the bank voltage method and the current interruption method are discussed separately. Conclusions and recommendations for future work are summarized in Chapter 5.

CHAPTER 2

BASICS OF ELECTRICAL AND CHEMICAL MEASUREMENTS

ELECTRICAL MEASUREMENTS

A typical capacitor-discharge circuit for the exploding wire test is shown in Figure 1. After the circuit is closed by a fast switch S, the electrical energy is stored efficiently in the inductor and an exploding wire in water becomes the main resistance component R. The period of current oscillation τ and the peak current I_p are determined by adjusting capacitance C of the capacitor bank, its voltage V_c , and inductance L of the circuit as shown in

$$\tau = 2\pi\sqrt{CL} \quad (1)$$

$$I_p = V_c \sqrt{\frac{C}{L}} \quad (2)$$

When the wire explodes, the voltage across the wire increases fast due to the sudden increase of the wire resistance or the fast decay of current according to

$$V = iR = L \frac{di}{dt} \quad (3)$$

The voltage surge can occur very close to the time of peak current by adjusting wire mass m and a given set of C, V_c , and L. Such an arrangement efficiently delivers the stored energy to the wire.

The dissipated energy E_d through the test wire up to time t after the circuit is closed can be expressed by

$$E_d(t) = \int_0^t i(t') V(t') dt' \quad (4)$$

where $i(t')$ denotes current-time profile through the wire and $V(t')$ voltage-time profile across the wire. Time t at which current stops flowing is determined by

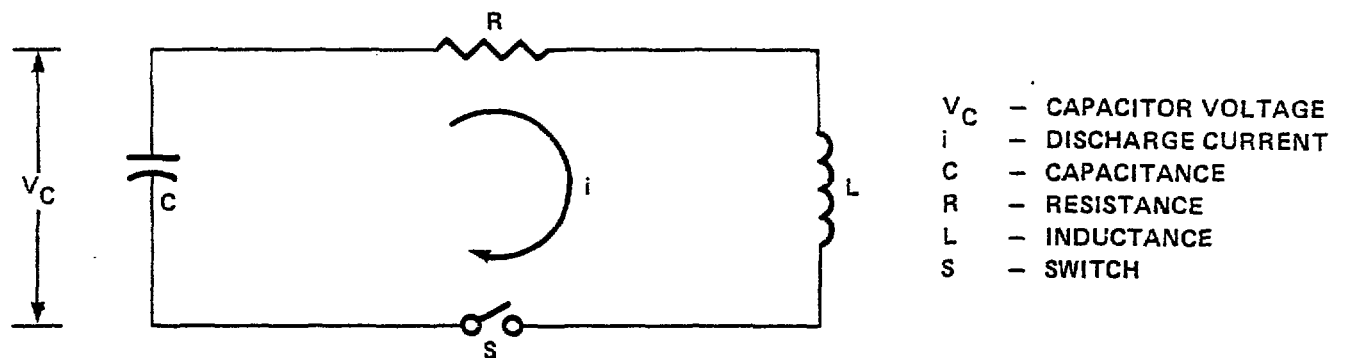


FIGURE 1. EQUIVALENT CIRCUIT FOR CAPACITOR-DISCHARGE CIRCUIT

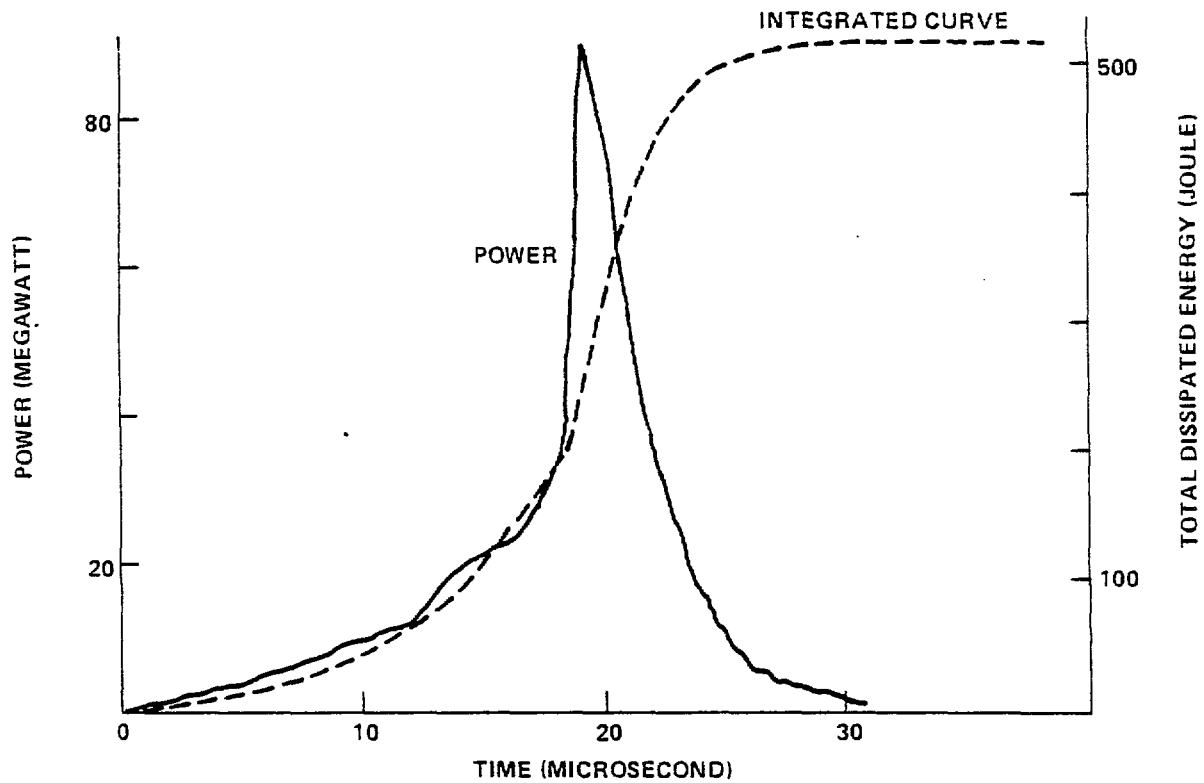
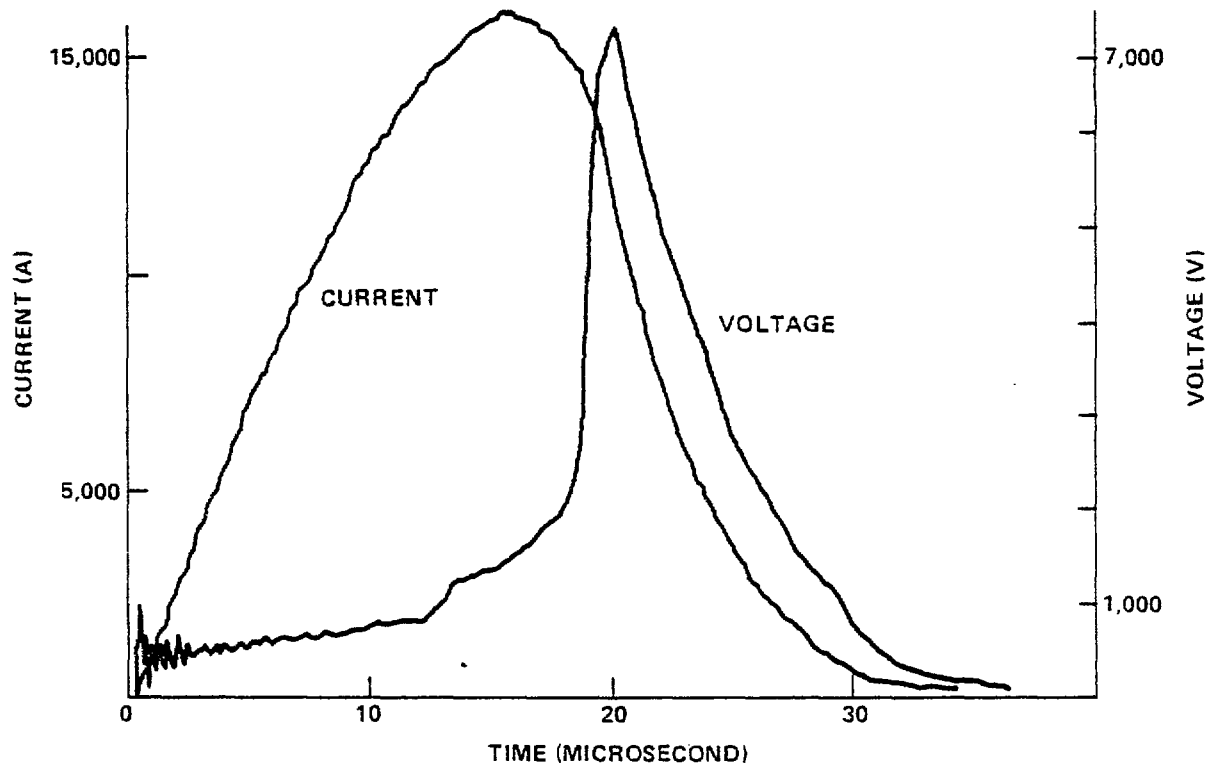


FIGURE 2. TYPICAL WAVEFORMS OF CURRENT, VOLTAGE, POWER, AND TOTAL DISSIPATED ENERGY FOR ELECTRICAL EXPLOSION OF ALUMINUM IN WATER

either a natural decay of current or a forced interruption through provision of a bypass around the wire. Typical i - t , V - t , $i \cdot V$ - t , and E_d - t profiles of aluminum explosion are shown in Figure 2.

For a simplistic case in which the heat loss due to cooling of the test wire and the energy gain from the chemical interaction with water are neglected, the dissipated energy is directly related to temperature rise of the wire as

$$E_d = \int_{T_o}^{T_m} C_{p_s} \cdot m \cdot dT + \Delta H_f \cdot m + \int_{T_m}^T C_{p_l} \cdot m \cdot dT \quad (5)$$

In Equation (5), T_o , T_m , T denote initial, the melting and final temperature of the wire, C_{p_s} and C_{p_l} the specific heat of the wire at solid and liquid state,

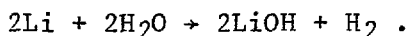
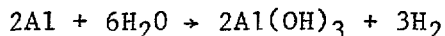
ΔH_f the heat of fusion, and m the wire mass. The temperature dependence of the physical constants is neglected and the final temperature is assumed not to have reached the boiling point of the wire. For the case in which the dissipated energy is adjusted to achieve only a partial vaporization of the wire material, the relationship between the energy and the wire temperature becomes

$$E_d = \int_{T_o}^{T_m} C_{p_s} \cdot m \cdot dT + \Delta H_f \cdot m + \int_{T_m}^{T_b} C_{p_l} \cdot m \cdot dT + \Delta H_v \cdot m \cdot f \quad (6)$$

where T_b denotes the boiling point of wire, ΔH_v the heat of vaporization and f the fraction of the wire vaporized. T_b depends on the gas pressure surrounding the molten wire.

HYDROGEN MEASUREMENT

The extent of the chemical interaction between the wire material and water is determined by measuring hydrogen gas product in the reacting system as shown in



Quantitative measurement of hydrogen gas can be done in a simple manner owing to the fact that the gas phase after the reaction consists of hydrogen and water vapor only. At a given temperature the vapor pressure is constant, and thus the hydrogen gas pressure in the system can be determined from the measurement of the total pressure. The number of moles of hydrogen is determined from the ideal gas law if the volume of the gas phase of the system after the reaction is known. Thermodynamic derivation of the equations for the measurement is based

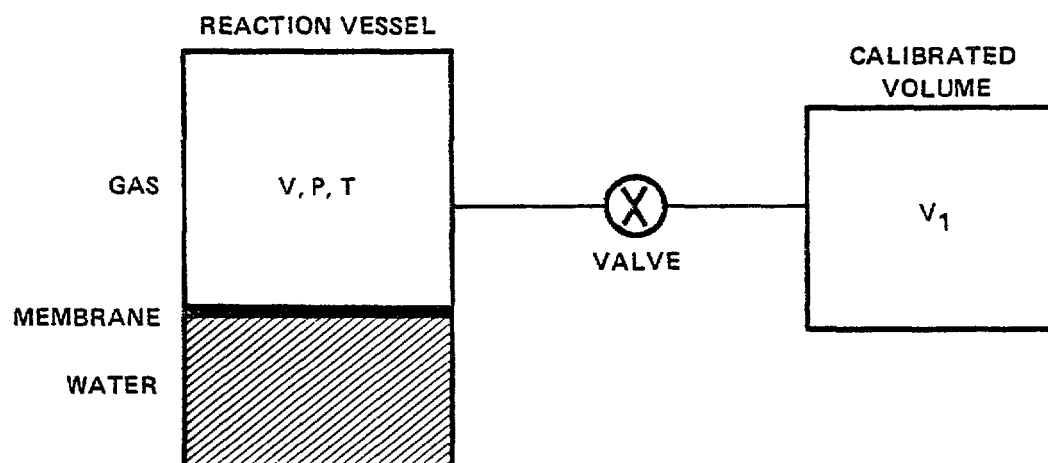


FIGURE 3. DETERMINATION OF GAS VOLUME (V) AFTER EXPLOSION. TOTAL GAS PRESSURE (P) REDUCES TO P' UPON OPENING OF THE VALVE THAT CONNECTS THE VESSEL TO A CALIBRATED VOLUME (v_1) UNDER VACUUM

upon a scheme illustrated in Figure 3. Before the reaction of the wire with water, both the reaction chamber and the calibrated container of volume V_1 are under vacuum with the valve between them closed. After the reaction, the vessel is filled with liquid water, water vapor, and hydrogen gas. The hydrogen gas dissolved in water at room temperature is negligible. After the system is in thermal equilibrium with the surroundings at temperature T , the total gas pressure P of the vessel is read. From the ideal gas law,

$$PV = nRT \quad (7)$$

where V denotes the volume of the gas phase, n the number of moles of gas molecules, and R the universal gas constant. P and n can be expressed in terms of individual contributions from the component molecules as shown in

$$P = P_H + P_W \quad (8)$$

$$n = n_H + n_W \quad (9)$$

where P_H , P_W , n_H , and n_W denote the partial pressure and the number of moles of hydrogen and water vapor, respectively.

When the valve is open, the pressure P of the reaction vessel decreases to P' due to flow of gases to V_1 . After the total system attains thermal equilibrium again, Equation (7) can be rewritten as in

$$P'(V+V_1) = n'RT \quad (10)$$

$$n' = n + \Delta n \quad (11)$$

$$P_W V_1 = \Delta n \cdot R \cdot T \quad (12)$$

where Δn denotes the increment of the number of moles of water vapor due to the provision of extra space V_1 . From Equations (7), (10), (11), and (12),

$$\frac{V}{V+V_1} = \frac{P'}{P} \cdot \frac{n}{n+\Delta n} \quad (13)$$

and

$$V = (afV_1 - \Delta n)/a(1-f) \quad (14)$$

where $a = \frac{P}{RT}$ and $f = \frac{P'}{P}$.

From Equation (14) the volume V is determined when P , T , V_1 , and P_W are known. Once V is determined, the number of moles of hydrogen molecule is obtained from Equations (7), (8), and (9) as shown in

$$n_H = n - n_W = \frac{V}{RT}(P - P_W) . \quad (15)$$

If Δn is negligible, V is simply expressed as

$$V = \frac{P'V_1}{P - P'} . \quad (16)$$

CHAPTER 3

EXPERIMENTAL

WIRE FABRICATION

Ingots of aluminum and aluminum-lithium alloy were prepared in a glove box under helium gas atmosphere first by melting pure aluminum and the master alloy (aluminum containing 6% zirconium) and then adding lithium. Zirconium concentration in the ingots was less than 0.15 weight percent. The ingots, after being removed from glove box, were wrapped in aluminum foil, homogenized by undergoing heat treatment for 16 hours at 530°C in forced air, and then machined down to 0.55" diameter. The machined rods were cold swaged down to 0.075" diameter with intermittent annealing at 300°C. Finally, wires were drawn down to 0.023" diameter (0.58 mm). The upper limit for Li concentration in drawing the alloy wire is about 2.8 weight % beyond which Al-Li intermetallic compounds start being precipitated.

The composition of the wire was confirmed by density measurements (water replacing method) and atomic absorption spectroscopy. Scanning electron microscopic pictures of wires were taken to examine the surface roughness and the uniformity of diameter. Electrical resistance of the wires was measured by Keithley 503 milliohmmeter.

REACTION VESSEL AND HYDROGEN MEASUREMENT

The reaction vessel used in this study is shown in Figure 4. The vessel consisted of basically four parts: the water container made of Nylon, the inner and the outer aluminum caps, and the base made of G-10 plastic. The two electrical leads made of brass rods were hermetically sealed to the base. Sample wire that was cut into 6, 7, or 10 cm long pieces was secured to the top of the leads with screws. The end portion of the wire was wrapped with thin copper foil. The total mass of the wire used in each test was between 40 and 150 mg.

Small bores were made on both the inner and the outer aluminum caps to provide a space (volume is about 70 ml) for the generated gases from the reaction between the wire and water. Deionized and degassed water was separated from the space by a thin membrane (10 mils thick plastic sheet) making sure that no air bubbles were trapped in the water.

The outer aluminum cap was connected to the vacuum line by a copper tubing welded to it. A calibrated container, the volume of which was 55 ml, was attached to one end of the vacuum line. Before the test, the air in the system was pumped out by a mechanical pump. Typical pressure range of the system

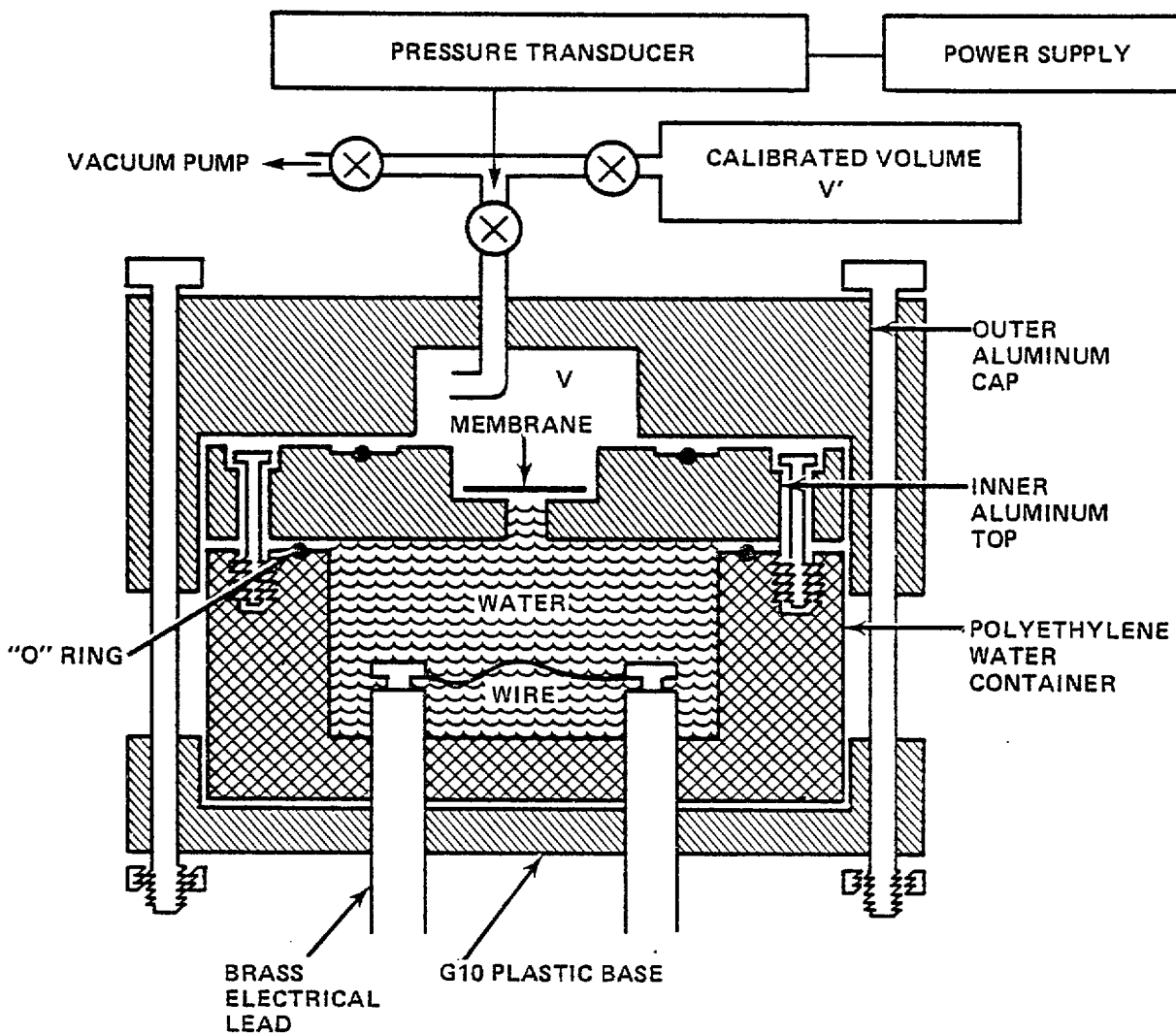


FIGURE 4. REACTION VESSEL AND MEASUREMENT OF HYDROGEN GAS

before initiating the test was about 200 millitons. After the wire explosion the whole system was allowed to come to equilibrium which took about 20 minutes and the pressure was read by a strain gauge type transducer (Whittaker Corp, in 15 psia range) with the valve at the calibrated container shut off. The pressure of the system was read again with the valve opened.

CURRENT PULSE GENERATION AND ELECTRICAL MEASUREMENTS

The electrical setup used in the tests is shown in Figure 5. The stored energy at the capacitor bank was released by using a spark gap switch that was triggered by a pulse generator (Pacific Atlantic Electronics Model PT55). The trigger unit (the pulse generator plus power supply) was activated by a signal from a time delay generator (Orthometric Inc., Model 308).

Total dissipated energy (heat) through the wire sample was adjusted by either varying the bank voltage or interrupting current by a crowbar switch. In the first method the voltage was varied from 3 to 5 kV with 50 μ F total capacitance. The rise time to peak current was about 20 μ sec. In the crowbar method the total capacitance was increased to 300 μ F. The rise time to the peak current was increased to 100 μ second by adding extra inductors. The crowbar firing circuit was activated by a delayed signal from the time delay generator which also activates the main circuit. Closing of the crowbar was actually accomplished by an explosive (RP80) that makes an aluminum rod pierce across an insulator to contact another aluminum plate.

The current through the test wire was measured by a Pearson gauge that has a conversion factor of 0.005 V/A. The voltage across the wire was measured by a voltage divider. The signal noise ratio caused by a ground loop was minimized by disconnecting the AC ground of the power supply for capacitor charging from the scope ground. Current and voltage profiles were recorded and stored on a digital scope (Norland, model Prower). Triggering of the scope was synchronized to the main circuit.

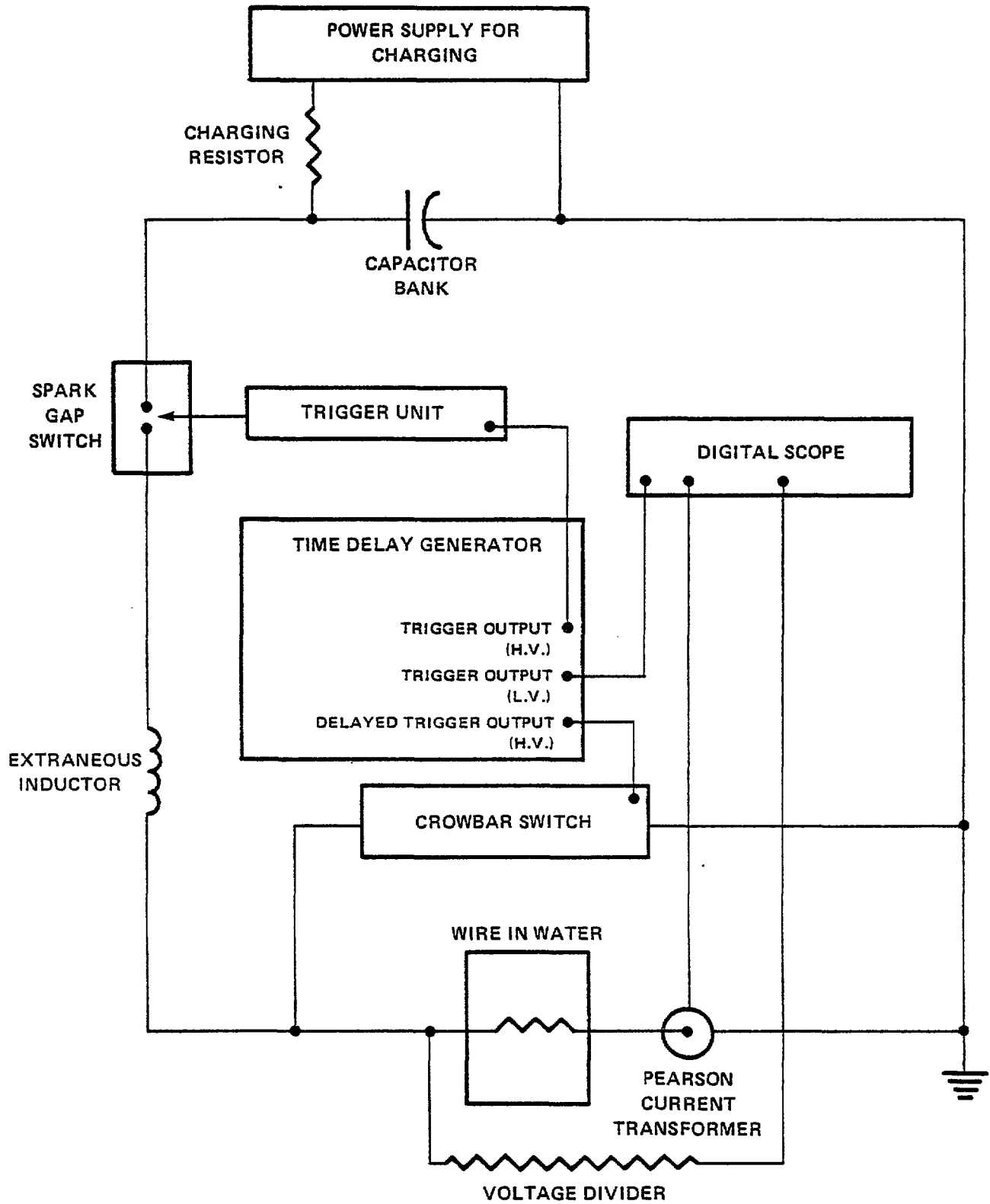


FIGURE 5. SCHEMATIC ELECTRICAL SETUP FOR EXPLODING WIRE EXPERIMENTS.

CHAPTER 4

RESULTS AND DISCUSSION

PHYSICAL PROPERTIES OF SAMPLE WIRES

SEM pictures of aluminum and its alloy wire are shown in Figure 6. It is seen that the diameter is uniform and there is not much difference in the surface roughness between the two wires though the alloy wire shows some localized roughness. The measured density, electrical resistivity, and the concentration of the component atoms of each material are presented in Table 1. From the results of the density measurements and the atomic absorption spectra, the lithium concentration of the alloy was confirmed to be 2.5 weight percent. The electrical resistivity data show that adding 2.5 weight percent of lithium to aluminum increases the resistivity by a factor of 2.5. According to Mathiessen's rule⁴ this ratio remains the same as temperature of the material increases. The resistivity of each material at liquid phase is about 1.6 times larger than solid phase⁴. The specific heat of the alloy was estimated from the values of the constituent elements. Since the alloy formation is an exothermic process, the latent heat of the alloy is expected to be higher than aluminum. As a result, the rate of temperature rise of the alloy in the initial phase of heating is expected to be slower than aluminum if the initial heating rates of the materials are the same.

The initial heating rates of the wires, Al and Al-Li, were adjusted to be the same by applying different bank voltages to counterbalance the higher resistivity of the alloy wire. Another way to adjust the difference in the resistivity is to make a thicker alloy wire to decrease its resistance. However, since the dispersing nature of the molten metals could depend on their physical size, the wire diameter was kept constant.

RESISTANCE CURVES

The first series of the tests were made to examine the resistance rise of the wires (~150 mg of mass). The current and voltage profiles of some wires are shown in Figure 7. The resistance curves obtained by dividing the voltage curves by the corresponding current curves are shown in Figure 8. Also shown in the Figure 8 are the profiles of the total energy dissipated through the wires.

TABLE 1. PHYSICAL CONSTANTS OF ALUMINUM AND
ALUMINUM-LITHIUM ALLOY

WIRE	SPECIFIC GRAVITY (GM/CC)	ELECTRICAL RESISTIVITY ($\mu\Omega \cdot \text{CM}$)	LITHIUM CONTENT BY ABSORPTION SPECTROSCOPY (WT %)	SPECIFIC HEAT AT 25°C (CAL/GM·°C)
ALUMINUM	2.74	3.4	0	0.215
Al-Li (2.5 wt. % of Li)	2.50	8.6	2.45	0.231

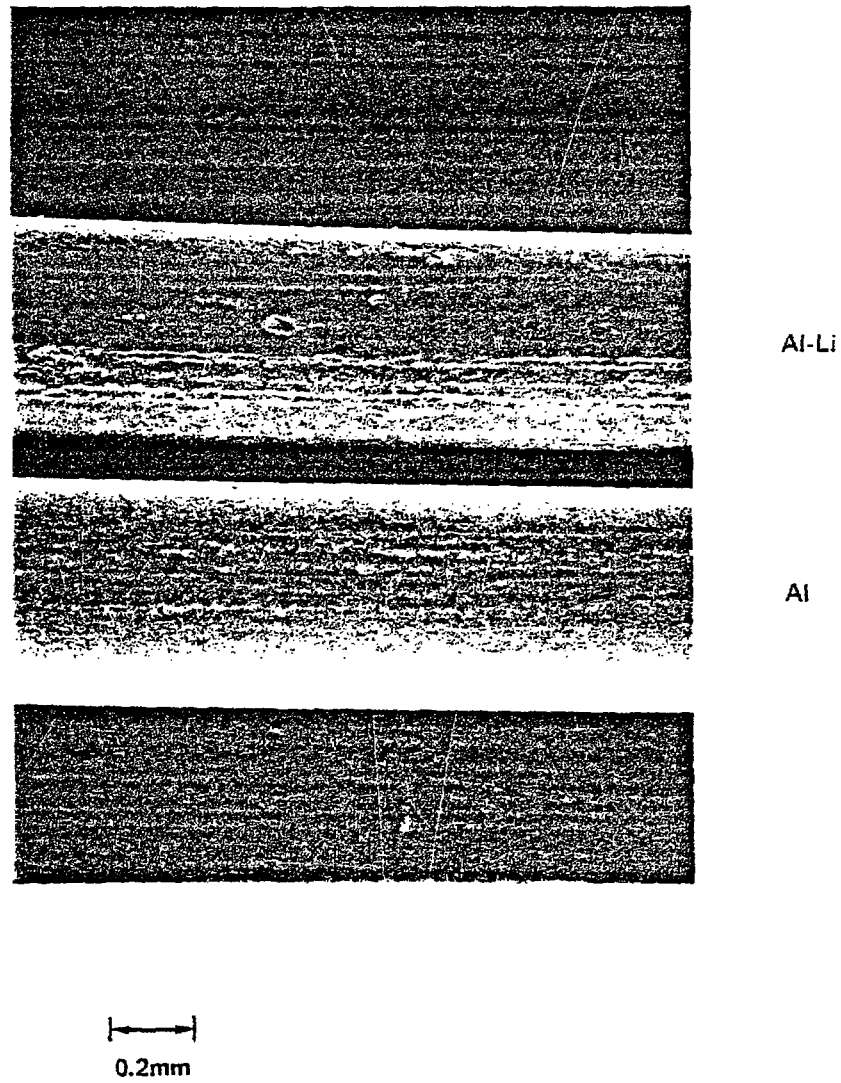


FIGURE 6. SEM PICTURES OF Al-Li AND Al WIRES

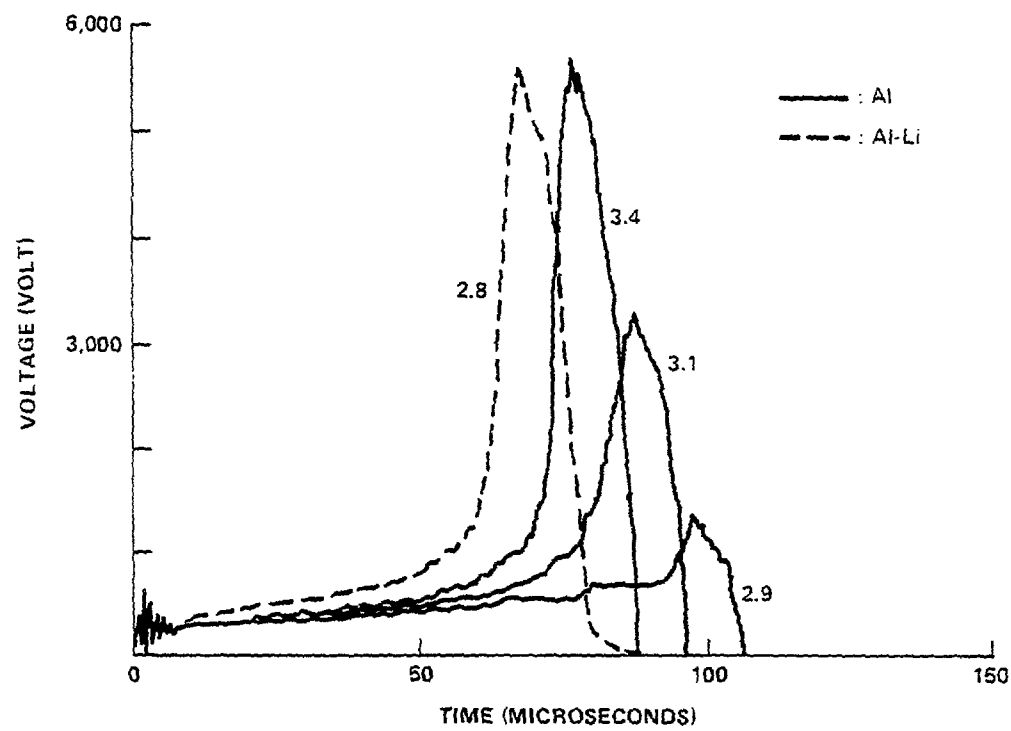
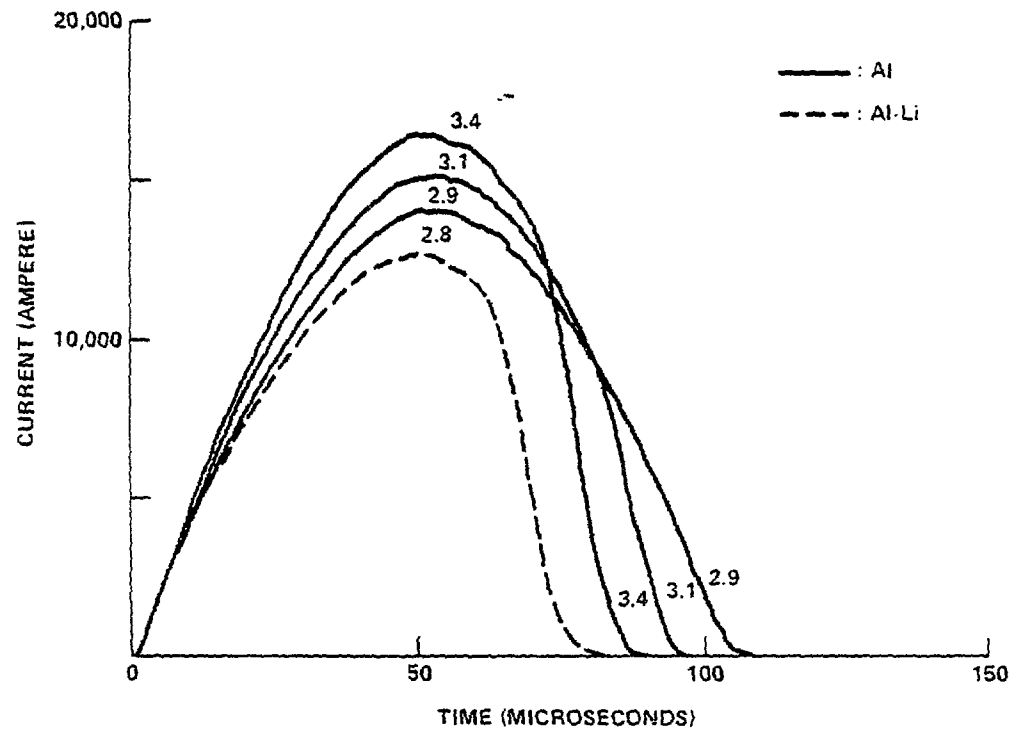


FIGURE 7. CURRENT AND VOLTAGE PROFILES OF EXPLODING WIRES FIRED AT DIFFERENT BANK VOLTAGES. THE NUMBER ON EACH CURVE DENOTES INITIAL BANK VOLTAGE.

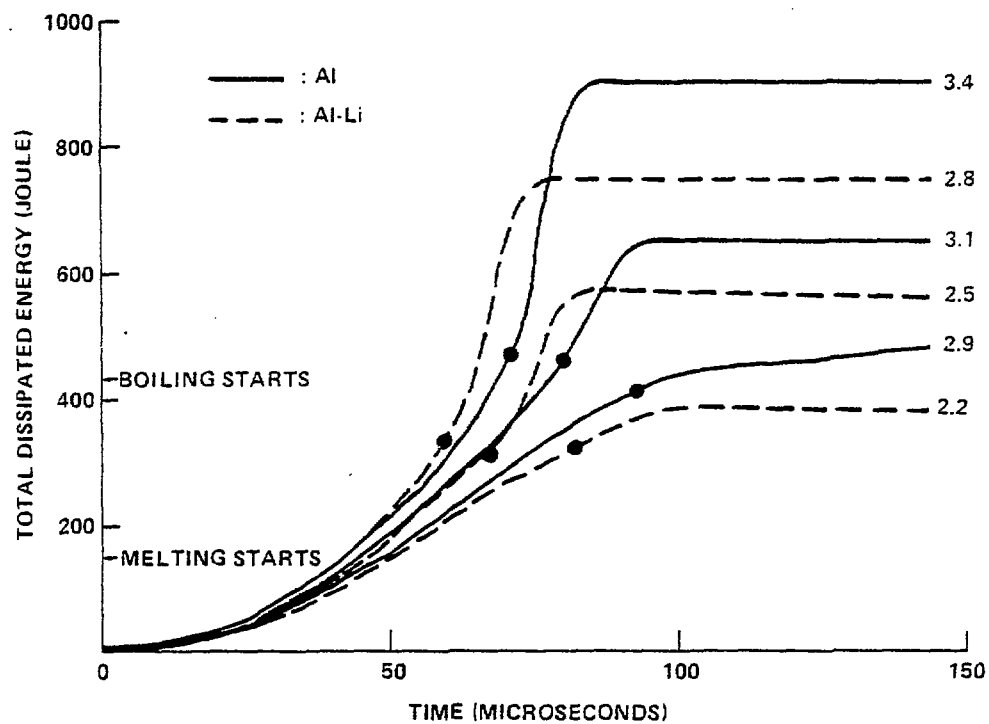
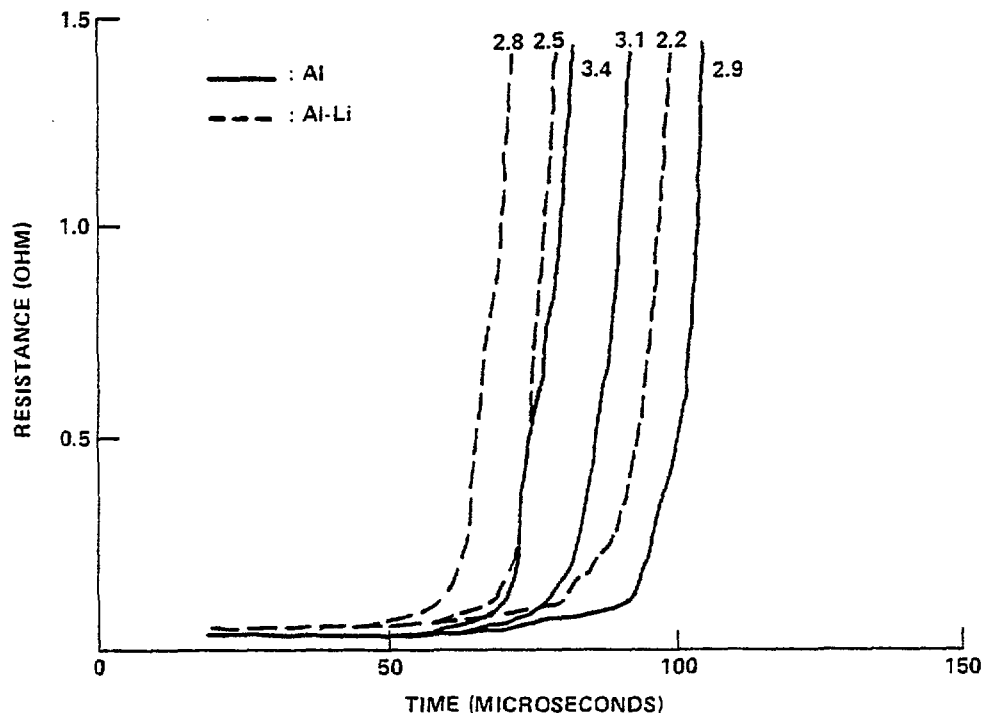


FIGURE 8. RESISTANCE AND TOTAL DISSIPATED ENERGY PROFILES OF EXPLODING WIRES. (THE NUMBER ON EACH CURVE DENOTES INITIAL BANK VOLTAGE. THE ONSET OF MELTING AND BOILING PROCESS ARE INDICATED BY ARROWS ON THE ENERGY AXIS WHILE THE POINTS AT WHICH RESISTANCE SURGE OCCURS ARE SHOWN ON THE DISSIPATED ENERGY CURVES BY SOLID CIRCLES.)

The abrupt change of the resistance, coinciding with the sudden increase in the corresponding voltage profile, could be interpreted as the dispersion of the wire melt into water accompanied by the chemical reaction. As mentioned earlier, the fair comparison of Al and the alloy wire is possible only when their initial heating rates are equal. The exploding wires in this series of tests can be grouped into three pairs depending upon their initial heating rates (each pair has about the same initial rate.); Al (2.9 kv) and Al-Li (2.2 kv), Al (3.1 kv) and Al-Li (2.5 kv), Al (3.4 kv) and Al-Li (2.8 kv). It is seen from Figure 8 that the alloy wire in each pair registers the earlier rise (~ 15 μ seconds) in resistance.

The sudden increase in wire resistance coincides with the acceleration of the corresponding energy dissipation curve. These points are marked on the energy dissipation curve by solid circles as shown in Figure 8. Also on the energy axis are indicated the energies needed to start melting and boiling process of the wires. These energies are estimated from Equations (5) and (6) assuming that the boiling point is near 2400°C . The total energy (heat) that has been dissipated through the alloy wires until the acceleration is about 1 kJ/gm larger than the energy through Al wires. These results indicate that the alloy wires explode earlier with less energy than the corresponding Al wires provided that their initial heating rates are equal.

REACTIVITY FROM HYDROGEN MEASUREMENTS

The extent of the reaction was determined quantitatively by measuring the hydrogen gas product from the reaction as a function of the dissipated energy.

Bank Voltage Method

The test results are summarized in Table 2 and Figure 9. The consistency of the measured volume V in Equation (14) is a good criterion determining the accuracy of the measurements. The total error in the chemical measurements is estimated within $\pm 4\%$.

The results show that up to the input energy of 8 kJ/gm the alloy wire shows higher conversion percentage than aluminum wire. At 8 kJ/gm, both materials completely reacted with water. However, a fair comparison of the reactivity becomes possible only when their initial heating rates are the same. The rate for aluminum wire is very close to that for the alloy wire in the two pairs of the tests in Table 2, aluminum at 4.5 kV and the alloy at 4 kV for one pairs and aluminum at 4 kV and the alloy at 3.5 kV for the other. In these two pairs the alloy wire still shows higher conversion, 94% vs. 84% and 70% vs. 39%, respectively.

The relationship in Figure 9 contains an uncertainty as to what portion of the input energy is actually contributed to induce the chemical reaction. Because the current collapse from the wire explosion has a certain decay time,

TABLE 2. TOTAL DISSIPATED ENERGY AND CHEMICAL CONVERSION OF
EXPLODING WIRES FIRED AT DIFFERENT BANK VOLTAGES

SAMPLE WIRE*	BANK VOLTAGE	DISSIPATED ENERGY (kJ/GM)	HYDROGEN GENERATED (MILLIMOLES)	CHEMICAL CONVERSION (%)
Al	3.0	2.3	0.45	17
Al	4.0	3.7	1.1	39
Al	4.5	5.9	2.4	84
Al	5.0	8.0	2.8	100
Al-Li	3.0	2.6	1.0	40
Al-Li	3.5	3.5	1.8	70
Al-Li	4.0	5.6	2.5	94
Al-Li	5.0	11	2.7	100

* Al = 50 mg
Al-Li = 48 mg

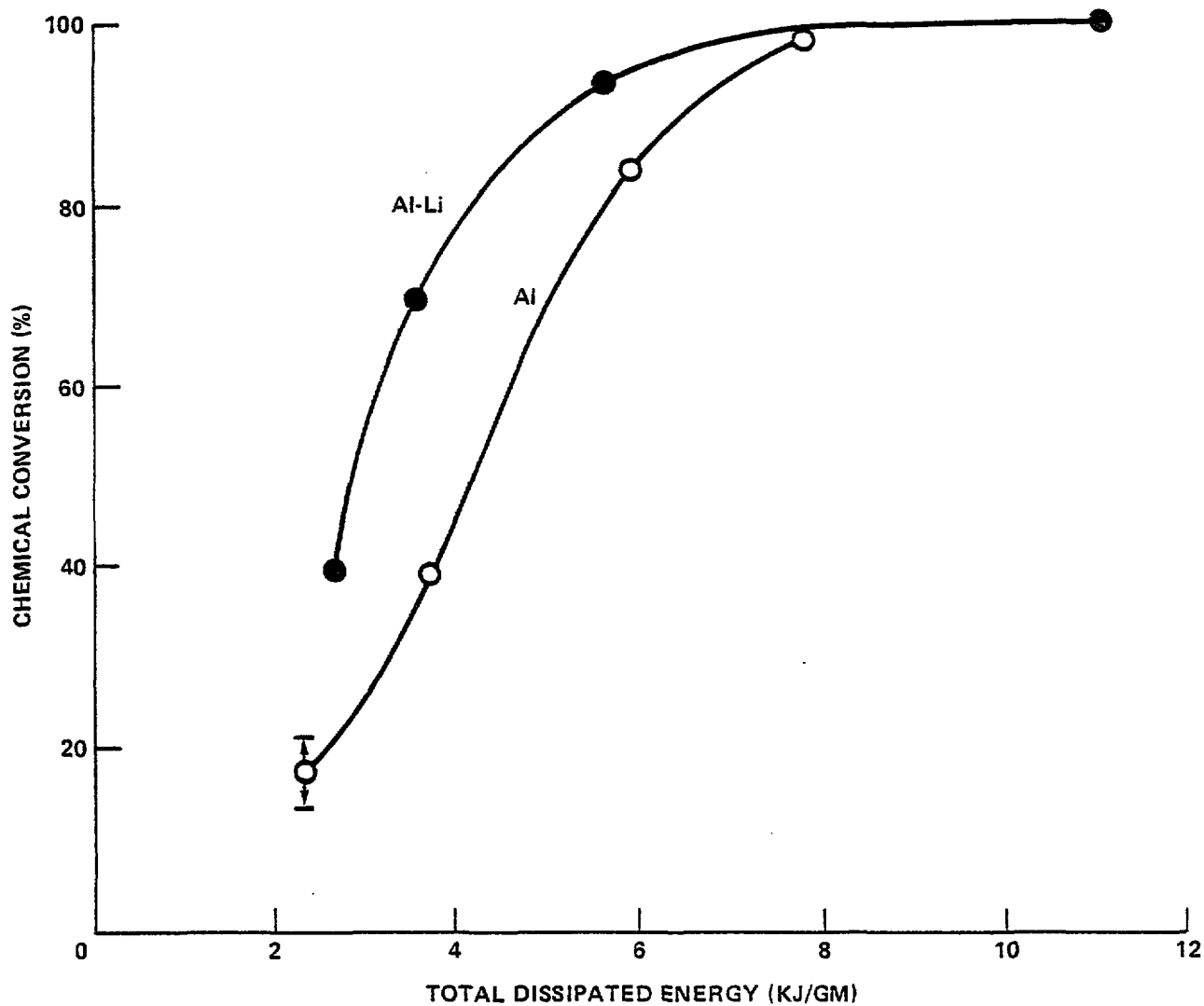


FIGURE 9. FRACTION OF EXPLODING WIRES THAT UNDERWENT CHEMICAL REACTION WITH WATER AS A FUNCTION OF DISSIPATED ENERGY. THE ENERGY WAS CONTROLLED BY VARYING CAPACITOR BANK VOLTAGE

there is a possibility that some electrical energy is discharged during the current collapse without contributing to the reaction. Therefore, a regulation of the input energy becomes necessary in order to obtain a more accurate relationship between chemical conversion and input energy. Hydrogen measurements by a refined energy control is discussed next.

Current Interruption Method (Crowbar Switch Method)

The typical profiles of current, voltage, and the total dissipated energy profiles by this method are shown in Figure 10. The number on each curve denotes the delay time set on the delay generator for current interruption. Little variance among the curves indicates the consistency of the electrical measurements. The results of the chemical measurements are summarized in Table 3 and Figure 11. The relationship shown in Figure 11 differs from the one in Figure 9 in that the reactivity of the alloy wire rises very steeply up to a threshold energy. The reactivity beyond the threshold energy is minimal. The reactivity of aluminum wire increases rather monotonically with the increase of the energy up to about 10 kJ/gm. This result implies that for the case of the alloy wire the current interruption method can save a large amount of electrical energy in achieving the full chemical reaction. Once a critical energy is supplied to the wire, the further dissipation of energy does not contribute to the reaction.

The voltage surge manifests opening of the wire due to dispersion of the molten metal or the vapor metal within the surrounding water. The dispersion results in large surface contact between the wire material and the water. Therefore, a significant chemical reaction between them takes place during the surge. Examination of the relationship between the dissipated energy and the chemical conversion indeed confirmed that the heat dissipation during the time of the voltage surge effectively contributes to the chemical conversion. The relationship between the conversion and the duration of current flow through the wires is shown in Figure 12. The energy which contributes to the chemical conversion is dissipated during a very short time span, approximately 15 μ seconds for the alloy and 30 μ seconds for Al. This could imply that the exploding alloy wire is dispersed more readily within water than the exploding Al wire. A slowly dispersing wire material can still let the electrical current flow thus letting more energy be dissipated. The time span does not give any information as to the actual chemical reaction time. It only means that the energy dissipated through the wires before or after the span does not trigger the chemical reaction or extend the degree of the chemical conversion.

It is proposed that the difference in the shape of the curves of the two materials in Figures 11 and 12 be explained by the existence of a self-sustaining mechanism in the mixing of the alloy melt with water. The alloy, once having reached the critical temperature and gained the critical injection speed, could sustain a self-dispersive effect through the water medium and achieve enough contact with water to complete the reaction. Al wire which lacks such a self-sustaining mechanism requires a continuous supply of energy to achieve fine dispersion through water. Complete chemical conversion of the Al

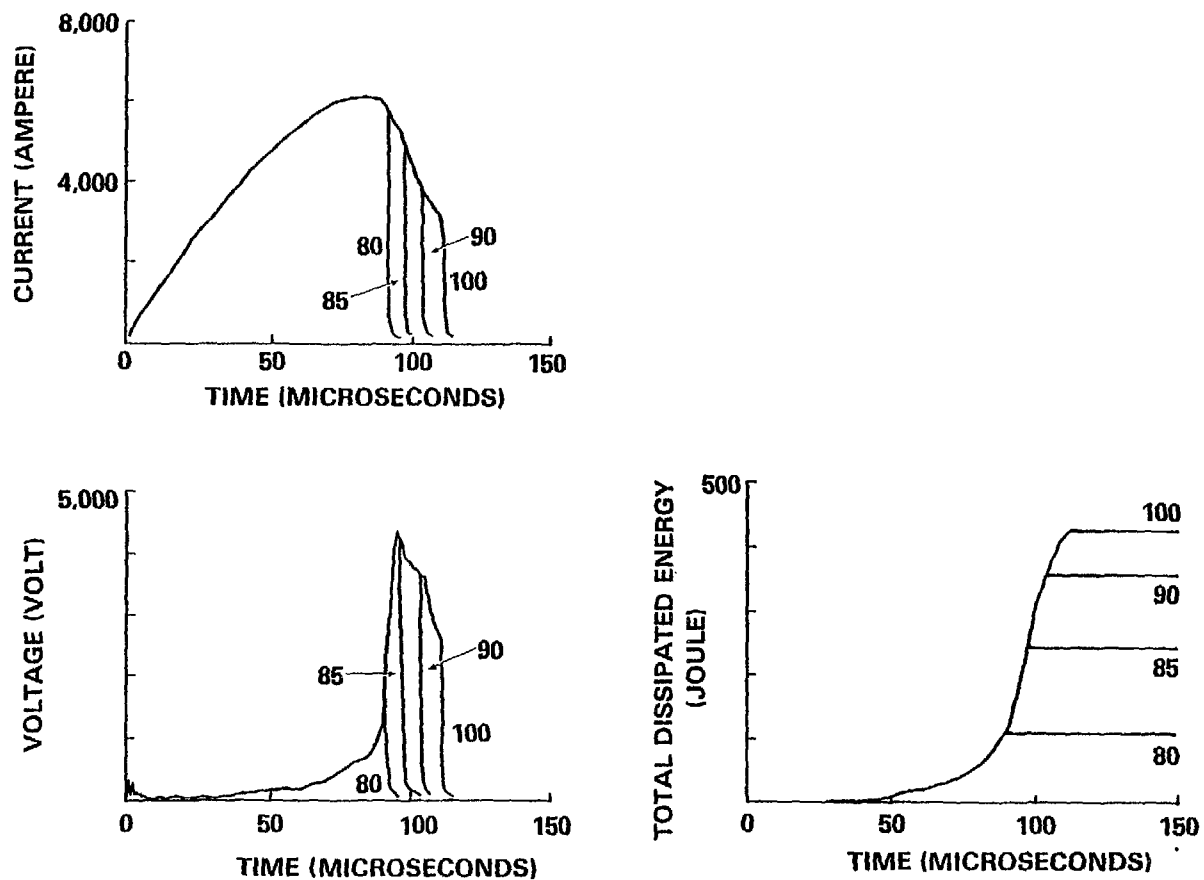


FIGURE 10. TYPICAL CURRENT, VOLTAGE, DISSIPATED ENERGY PROFILES OF THE EXPLODING ALUMINUM-LITHIUM ALLOY WIRES FIRED AT A FIXED BANK VOLTAGE WITH DIFFERENT CURRENT INTERRUPTION TIME. (THE NUMBER ON EACH CURVE DENOTES THE TIME AT WHICH CURRENT INTERRUPTION WAS MADE AFTER THE MAIN CIRCUIT IS CLOSED.)

TABLE 3. TOTAL DISSIPATED ENERGY AND CHEMICAL CONVERSION OF
EXPLODING WIRES FIRED AT A FIXED BANK VOLTAGE
WITH DIFFERENT CURRENT INTERRUPTION TIME

SAMPLE WIRE*	BANK VOLTAGE (kV)	DURATION OF THE DISCHARGE CURRENT UNTIL ITS INTERRUPTION (μ *SECONDS)	DISSIPATED ENERGY (kJ/GM)	HYDROGEN GENERATED (MILLIMOLLES)	CHEMICAL CONVERSION (%)
Al	3.0	92	2.2	0.45	20
Al	3.0	100	3.7	1.1	44
Al	3.0	103	5.2	1.7	73
Al	3.0	107	7.5	2.2	92
Al	3.0	110	10.4	2.4	100
Al	3.0	112	10.8	2.4	100
Al-Li	2.5	81	2.1	0	0
Al-Li	2.5	88	2.8	0.77	35
Al-Li	2.5	92	2.7	1.5	66
Al-Li	2.5	95	4.1	2.0	90
Al-Li	2.5	98	6.8	2.2	96
Al-Li	2.5	106	9.0	2.1	96
Al-Li	2.5	112	10.7	2.1	95

* Al = 42 mg
Al-Li = 40 mg

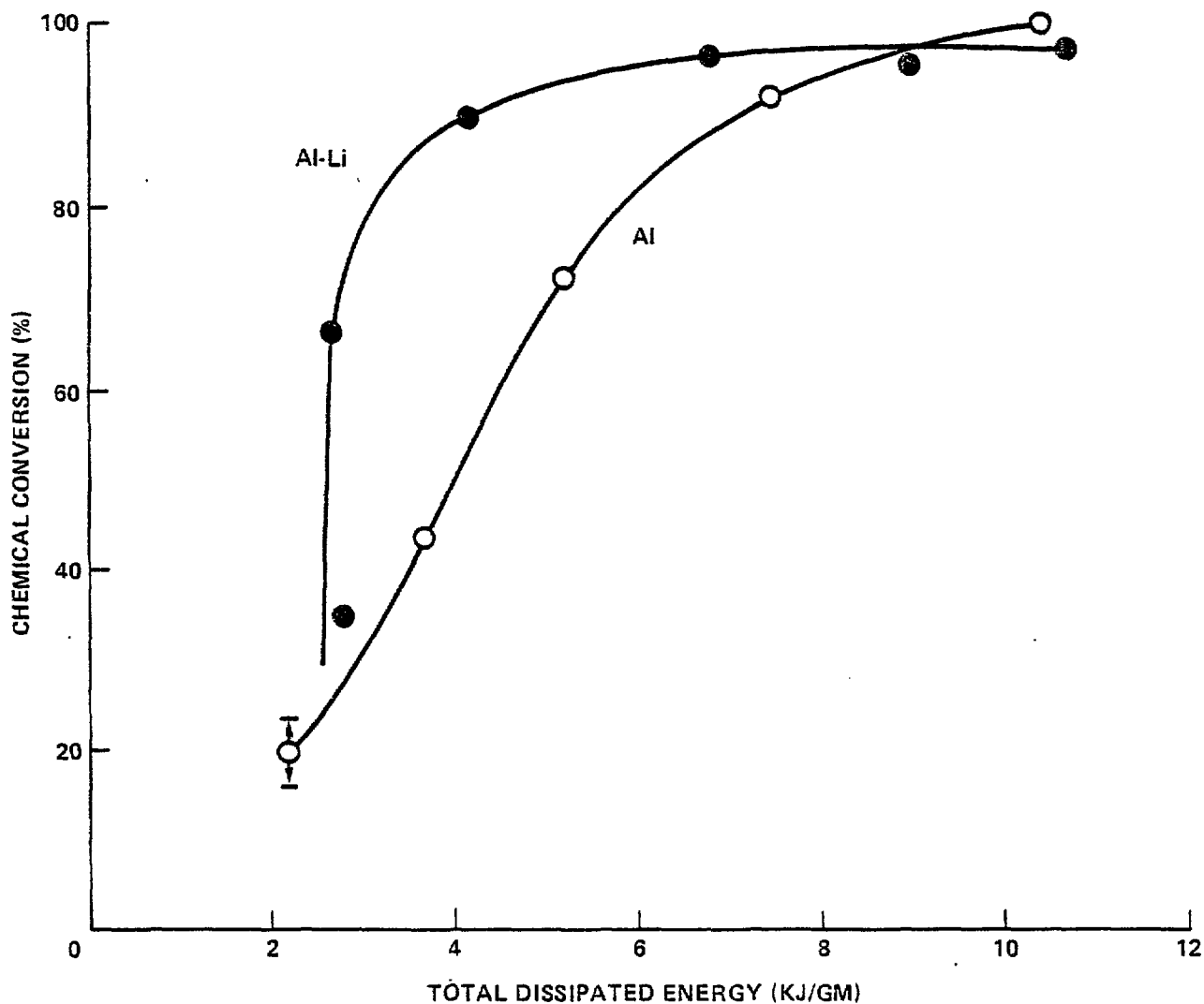


FIGURE 11. FRACTION OF EXPLODING WIRES THAT UNDERWENT CHEMICAL REACTION WITH WATER AS A FUNCTION OF DISSIPATED ENERGY. THE ENERGY WAS CONTROLLED BY CURRENT INTERRUPTION METHOD.

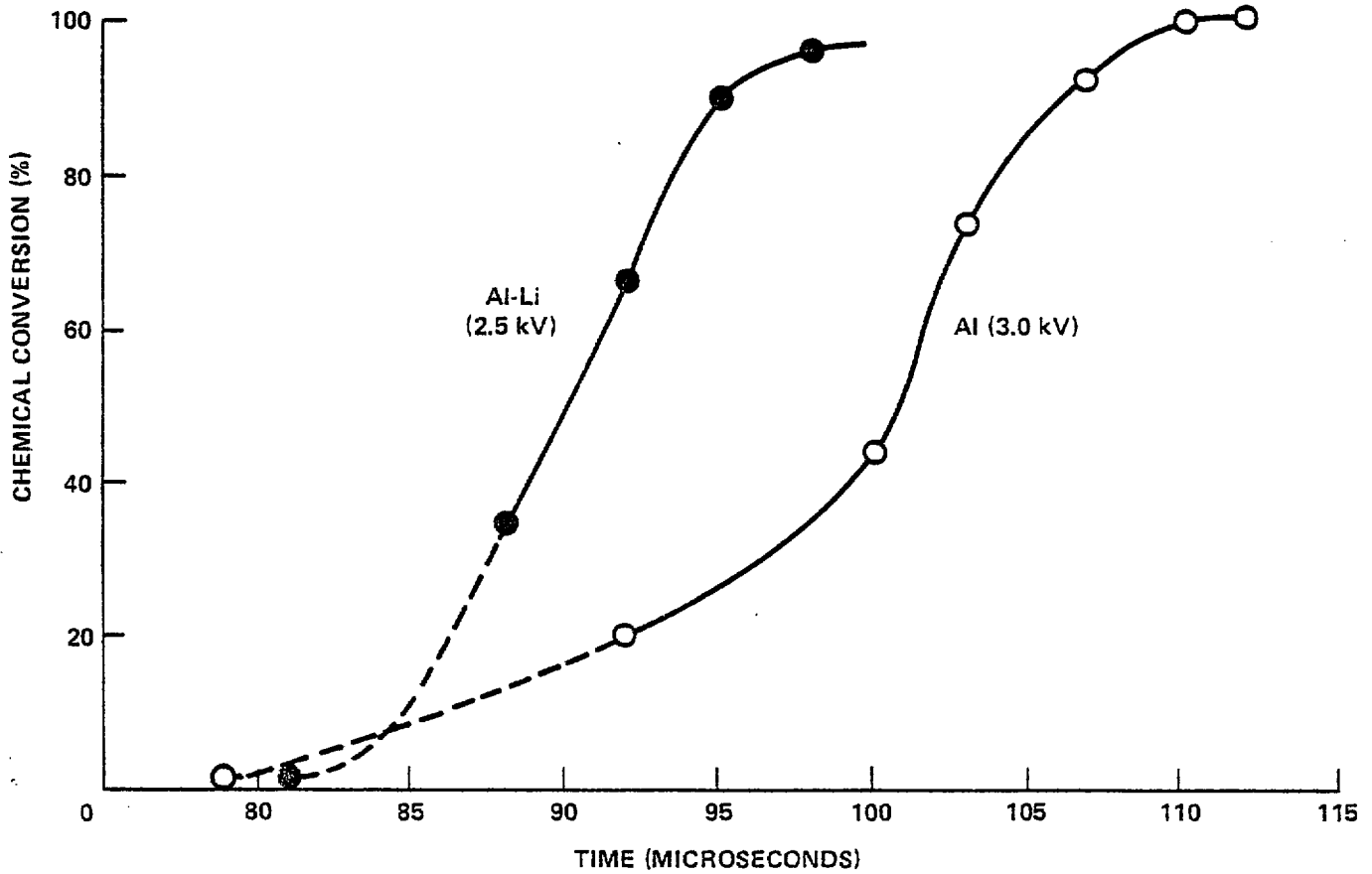


FIGURE 12. THE EXTENT OF CHEMICAL REACTION OF EXPLODING WIRES WITH WATER AS A FUNCTION OF THE DURATION OF THE DISCHARGE CURRENT

wire was made with the input energy which can fully vaporize the material. The injection speed of the melts into water depends on the magnitude of the shock wave generated inside the wires during the electrical heating. The self-sustained dispersion could be explained by the modified surface structure of the alloy by Li.

Rough conversion of the dissipated energy through the wires to temperature shows that no significant chemical reaction takes place for either material below 2000°C that is about the melting point of aluminum oxide.⁵ However, the estimation of the reaction temperature is difficult due to not only the heat loss to the surrounding water and the gain from the chemical reaction but also an inhomogeneous heating (geometrically) that is inherent to exploding wires.

One point to be mentioned is the validity of the exploding wire technique applied to aluminum-water interaction. A difficulty was pointed out in Reference 6 because of the ready oxidation of aluminum in water medium that could cause an arcing problem. Within the experimental parameters in this study no difficulties were encountered in conjunction with the arcing problem.

CHAPTER 5

CONCLUSIONS AND FUTURE WORK

The exploding wire technique incorporating a crowbar current interruptor and inductive energy storage worked well for the study of the molten aluminum water system. This technique enabled us to establish a well defined relationship between an electrical input energy and the chemical conversion of the metal.

The relationship revealed that a small concentration of Li in an Al-Li alloy (2.5 weight % of Li) has a profound effect on its reactivity with water. The alloy wire reacts with water almost completely with an input energy of 4 kJ/gm, whereas Al wire needs an energy of 10 kJ/gm to complete the reaction. Such difference in the chemical reactivity may well be explained by the existence of a self-sustaining mechanism in the mixing of the alloy melt with water. Therefore, the chemical tailoring of aluminum metal by metallurgical additions seems to be a promising way to enhance its reactivity with water.

One of the critical experiments that needs to be done is to examine the effect of an external perturbation to the metal melts on the reactivity with water. Such a test can be done by generating a shockwave near the test metal wire when its temperature is far below the boiling point. It is also worth investigating the reactivity of wires of different chemical composition and physical size by adding different alloying elements, e.g. magnesium and varying the wire diameter.

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