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WITH OXYGEN THROUGHPUT

TECHNICAL REPORT ME-RT 67007

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July 1967

DEPARTMENT OF THE NAVY
OFFICE OF NAVAL RESEARCH, POWER BRANCH

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DEPARTMENT OF MECHANICAL ENGINEERING

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ABSTRACT

Combustion of aluminum with oxygen was experimentally studied in the porous-plug configuration. Porous aluminum plugs of different internal structures and void contents were burned at atmospheric pressure with O_2 passed up through the specimens to emerge at the burning surface. Burning was achieved for an overall fuel-oxidant equivalence ratio variation of a factor of 4; burning surface regression rates approached 1 inch per second! Periodic accumulation and ejection of burning surface material at low O_2 throughput levels appeared similar to that exhibited by some aluminized solid propellant and hybrid propellant rocket motors. The results indicate that a porous-metal hybrid approach represents possibly the best means of achiev'ng the ultimate performance potential of a chemical rocket motor.

BACKGROUND AND INTRODUCTION

The most efficient chemical rocket propellant system has been calculated (Ref. 1) to be a mixture of 27% hydrogen, H_2, 47% oxygen, O_2, and 26% beryllium, Be, by weight, assuming complete combustion before the products are expelled. It appears that combustion of propellant systems containing such large percentages of metals is best achieved in the porous-metal type of hybrid rocket motor (Ref. 2), schematically compared with the conventional hybrid motor in Fig. 1. This paper reports the results of an experimental study of porous-metal combustion in the porous-plug configuration.

A porous-plug burner technique has been employed previously in studies of the combustion mechanism of nonmetallized composite solid propellants (Ref. 2 and 3). The metallic porous-plug burner technique was thought to be the best available means of simulating the combustion characteristics of composite solid propellants heavily loaded with metallic additives and, in particular, the very heavily loaded systems being considered for air-augmented rocket systems (Ref. 4) especially insofar as surface geometry and temperature are concerned. The ignition and burning of: (1) electrically heated wires in a cold gas (Ref. 5); and (2) cold particles injected into a hot gas (Ref. 6) appear to be less suitable, for example. Thus, the results of the present work might lead to an improved understanding of certain aspects of metallized composite solid propellant combustion, as well as metal combustion <u>per se</u>, in addition to providing preliminary design data for porous-metal hybrid rocket motors.

The authors' laboratory is not equipped to permit safe experimentation with explosion-hazardous H_2 or toxic Be. On the other hand, aluminum, Al, like Be, has a large heat of reaction with O_2 (Ref. 1) and is widely employed as a fuel in operational solid propellant rocket motors. The combustion characteristics of Al appear to be somewhat similar to those of Be (Ref. 5 and 6). Therefore the $Al - O_2$ system was studied, and it was hoped that the results of the subject work might provide a general basis for preliminary design of a porous-Be hybrid motor, as well as a specific basis for the preliminary design of a porous-Al hybrid motor.

Aluminum porous-plug burners of various types have been produced in the authors' laboratory. They consist of a porous bed of Al through which a flow of gaseous O_2 is passed to support combustion as it emerges at the burning surface. A number of techniques have been employed in their construction in order to assess the effects of physical structure on combustion characteristics, but the use of cement or bonding agent has been eschewed in order to keep the chemical aspect at the simplest possible level.

EXPERIMENTAL APPROACH

Figure 2 is a schematic representation of the experimental arrangement employed in the subject investigation. The porous-fuel elements were fabricated in the form of cylinders (3/8" diameter x 3" long) and securely mounted in either Plexiglas or quartz tubes. Three enameled copper timing wires (0.15" diameter) were threaded through the mounted specimens at 2" intervals the access holes were sealed with a modicum of epoxy resin. Ready variation of the O_2 flow through the burners (between 1.4×10^{-3} and 7.1×10^{-3} lb/in^2-sec.) was achieved by means of an acetylene torch (or a metallized solid propellant igniter charge on top of the burner) and the surface regression rate was obtained from measurement of the time interval between burnout of the timing wires. The burnings were often recorded cinematographically, permitting detailed study of the combustion process and providing an additional means of obtaining regression rate data.

All tests were conducted at atmospheric pressure.

FABRICATION OF ALUMINUM POROUS PLUGS

In order to fabricate test specimens without the use of chemically extraneous cements or bonding agents that might interact with the $Al-O_2$ combustion process, but with a wide range of physical characteristics, it was necessary to employ a number of different techniques. (Note: The Plexiglas tubing was observed to burn under all conditions. However, the burning Al surface was always at least 1" "ahead" of the Plexiglas - O_2 flame, so it can be safely assumed that the latter had no influence on the former.)

Fashioning of permeable media can be approached in one of two ways - casting of molten bulk material into a porous form, or aggregating a cluster of individual masses. The former involves quite sophisticated techniques in order to provide judiciously for the desired interconnected pore structure. The latter, for the specific case of granular Al, is complicated by the tenacious, omnipresent alumina film. Three types of porous Aℓ structures were employed during the subject program: compressed "wool", bonded spherical powder and cast mesh.

Aluminum "wool" (75 μ and 150 μ fiber diameter supplied by Carey Electronics Corporation, Springfield, Ohio, and 20 μ fiber diameter supplied by Sylvania Photolamp Div., New York, N. Y.) was compressed radially in a special press that was designed to produce 3/8" diameter, 3" long porous-plugs. The initial "wool" loading density was varied in order to produce cylinders with a void content ranging between 40% and 80%, i.e., having density fractions between 1/2 and 1/5 that of solid Aℓ .

The void content of a regular array of spheres of the same size is approximately 25% and is independent of the sphere size. Spherical Aℓ powder (supplied by Valley Metallurgical Co., Essex, Connecticut), approximately 125 μ in diameter, was loaded into a rig, hand-tapped, and exposed to a wash of 10% HCℓ /90% H_2O solution for approximately 5 minutes; this produced, after drying, a point-of-contact-bonded porous-plug in the standard cylindrical geometry noted previously with a void content of 40%.

The Metallurgy Laboratory of the Frankford Arsenal, Philadelphia, Pa., through the good offices of Mr. S. Lipson, prepared a number of Aℓ cast mesh (150 μ cell size, 55% void content) cylinders of the standard size. The imaginative casting method by which this form of porous Aℓ was prepared is due to Lipson (Ref. 7).

Photomicrographs of each type of structure are displayed in Fig. 3.

RESULTS AND CONCLUSIONS

In the subject program, the equivalence ratio was formulated in the following way: The observed surface regression rate multiplied by specimen density (which is proportional to one minus the fractional void content) was taken as the rate at which Aℓ was made available for combustion. The availability of 0_2 for combustion was taken to be the measured rate at which it was passed through the test specimen. The equivalence ratio, $\Phi_{f/o}$, was formed by normalizing the ratio of Al availability to 0_2 availability by the stoichiometrically correct value-assuming $Al_2 0_3$ to be the only product of combustion.

This quantity is a meaningful thermochemical parameter for the correlation of combustion rate data in intimately mixed systems. Observation of unburned aluminum leaving the porous-plug surface, passing up the tube (and eventually falling on the laboratory floor nearby) means that $\Phi_{f/o}$ is not thermochemically meaningful in the present case. Nevertheless, it is a convenient parameter for display of the subject data, and has been employed for this purpose herein.

Aluminum "Wool" Combustion

Figure 4 displays the dependence of pressed "wool" porous-plug surface regression rate on $\Phi_{f/o}$ and fiber size, at a void content of approximately 60%. The regression rate exhibited by these plugs is about an order of magnitude greater than that exhibited by most solid propellants and about two orders of magnitude greater than that exhibited by most conventional(i.e., non-porous) hybrid motors, at atmospheric pressure (Ref. 2). Combustion inefficiency was observed to be somewhat severe, however.

At low oxygen throughput rates, molten, burning pools accumulated on the surface and, after growing to some critical size, were entrained and carried off by the flow. There appeared to be a certain periodicity associated with this process, presumably due to the time required for a critical pool size to form. At high throughput rates the droplet size leaving the surface was much reduced and the combustion process was more or less continuous in nature.

Since mixing and mass removal appeared to be important factors in the overall process, the dependence of regression rate on the state of flow through the plug was investigated. Following Reference 8, the pressure drop, ΔP, across and mass flow rate, G, through the plugs were correlated by

$$\frac{(\Delta P)^2}{G} = a + bG$$

where "a" and "b" are constants for a particular porous-plug. The appearance of "b" (for Reynolds number greater than 10, based on average pore diameter) is due to the fact that inertial effects are found to depend nonlinearly on throughput rate.

When orientation of the "wool" fibers was purposely varied from plug to plug, it was observed that "b" varied by a factor of 4 in a typical series of plugs of constant void content (42%) and constant fiber size (20μ). At constant G (2.8×10^{-3} lb/in^2-sec), the measured regression rates of these plugs were quite dependent on "b", increasing by a factor of 3 as "b" increased by a factor of 4.

Decreasing the "wool" fiber size, while holding void content approximately constant, increased the regression rate significantly (Fig. 4), increased data scatter (the state of flow became more sensitive to variation in fiber orientation from plug to plug) and at low O_2 throughput rates increased the tendency for "wormholing" --nonuniform propagation of combustion in narrow channels far ahead of the regressing surface. Qualitative observation of collected combustion products indicated no significant change in combustion efficiency (i.e., cursory inspection suggested that the fraction of unburned aluminum appeared to remain unchanged) despite the shift in $\Phi_{f/o}$ for maximum regression rate with decreasing fiber size. Further, the product agglomerate size appeared to decrease with decreasing fiber size.

The effect of void content on the deflagration rate of the "wool" porous-plugs was investigated, and the results are plotted in Figure 5. The large scatter is presumably due to a high sensitivity of deflagration rate to fiber orientation and packing density. Nevertheless, it was possible to determine that, with all other conditions constant, the porous Aℓ "wool" plugs regressed faster when fashioned into a higher void content configuration; and the total Aℓ surface consumption (not combustion) rate--the product of surface regression rate and plug density--was increased as well.

Aluminum Bonded Powder Combustion

The Aℓ powder bonding process resulted in a great deal of variation in the character of the specimens produced, as evidenced by their widely varying resistance to the oxygen throughput rate. For both sizes tested, 125μ and 150μ spheres, the scatter in regression rate data was severe, and the permeability was so low that it was impossible to produce data at values of $\Phi_{f/o}$ less than about 2.5. All bonded powder specimens exhibited sporadic ejection of molten metal from the surface; subsequent recovery and examination revealed that the products contained mostly unburned Aℓ . For conditions that were roughly comparable, the bonded powder exhibited a regression rate approximately half that of the compressed "wool" (Figure 6).

Aluminum Mesh Combustion

Combustion of the Aℓ mesh proceeded smoothly, without agglomeration and ejection of a molten surface layer, and apparently with a much higher efficiency (based on a cursory examination of unburned metal content in recovered combustion products) than the "wool" or bonded powder, for $\Phi_{f/o}$ less than about 2.5. At higher values of $\Phi_{f/o}$, periodic agglomeration and ejection of molten metal from the surface was evidenced.

The regression rate data are displayed in Figure 6. Apparently the $\Phi_{f/o}$ for maximum regression rate lies somewhere around 1.5, whereas for the "wool" it lies somewhere around 2.5. If it is assumed that the surface regression rate is related to $\Phi_{f/o}$ by thermal energy transport processes, then it might be expected that the regression rate should reach a maximum near $\Phi_{f/o} = 1$, assuming that all of the chemical energy available is converted into thermal energy by the combustion process. Thus, the amount of shifting of the $\Phi_{f/o}$ for maximum regression rate to fuel-rich conditions then can be taken as an indication of the degree of incomplete combustion. This indication correlates qualitatively with the observed fraction of unburned aluminum in the combustion products of the aluminum mesh vis-a-vis that of the aluminum "wool".

SUMMARY

Porous Al plugs of void content between 40% and 80%, fashioned either by bonding spherical powders, by compressing "wool" fibers, or by casting a cellular mesh, were burned at atmospheric pressure with O_2 passed up through the specimens to emerge at the burning surface. Burning was achieved for an overall $\Phi_{f/o}$ (normalized Al-O_2 mass consumption ratio) variation of a factor of 4 or so. All tests were performed at atmospheric pressure and surface regression rates approaching 1 in./sec. were measured! The efficiency of combustion (not measured, but crudely estimated) appeared to vary widely with test conditions; although generally low, it seemed to be highest for the cellular mesh at O_2 throughput rates that produced a $\Phi_{f/o}$ of approximately 1.5; it seemed to be lowest for the bonded powder strands.

Certain findings of the subject program were generally consistent with those of Sutherland (Ref. 9), obtained by means of a similar technique but employing a different range of experimental parameter variation.

Below a certain threshold level of O_2 throughput, combustion appeared to proceed by means of "pool-burning" of molten Al on the regressing surface, and periodic ejection of these pools. At still lower rates "wormholing" was observed. However, above the threshold, combustion became smoother and the regression rate had a regular dependence on $\Phi_{f/o}$.

The periodic accumulation and ejection of burning surface material exhibited by the $A\ell$ porous-plug burner at low O_2-throughput levels appears to be similar to that exhibited by some aluminized solid propellant and hybrid rocket motors (Ref. 10). The porous-plug burner technique could provide a convenient means of studying this phenomenon, as well as aluminized propellant combustion <u>per se</u>.

Based on the data reported herein, preliminary design of an $A\ell/O_2$ porous-metal hybrid rocket motor operating at a combustion chamber pressure of 14.7 psi (a reasonable level for certain space applications) could proceed forthwith. By employing analogies between the combustion characteristics of the Be/O_2 system and the $A\ell/O_2$ system, the present work could be used as the basis for preliminary design of the Be/O_2 porous-metal hybrid motor. Nothing was revealed during the present program that casts doubt on the belief that the porous-metal hybrid approach currently represents the best practical means of achieving the ultimate possible performance of a chemical rocket motor. Indeed, it has been reinforced.

Natural extensions of the subject research include burning at elevated pressure levels and employment of different chemicals in both the solid and fluid phase, etc. Diagnostic tests should be undertaken in order to isolate from chemical factors the influence on regression rate of the state of flow within, and emerging from the porous-medium; for example, at a constant level of throughput rate, increasing fractions of oxidant could be replaced by a chemically inert fluid possessing similar physical properties, etc.

REFERENCES

1. Gordon, L. J. and Lee, J. B., "Metals as Fuels in Multicomponent Systems," American Rocket Society Journal, 32, 4, 600-606 (1962).

2. McAlevy, R. F., III and Lee, S. Y., "A Porous Plug Burner Technique for the Study of Composite Solid Propellant Deflagration on a Fundamental Level and Its Application to Hybrid Rocket Propulsion," AIAA Progress in Astronautics and Aeronautics: Heterogeneous Combustion, (Academic Press, N. Y., 1964), Vol. 15, pp. 583-608.

3. Burger, J. and Van Tiggelen, A., "Contribution a l'etude de la combustion des poudres composites," Memoires Academic Royale de Belgique, Tome 34, fac. 3 (1964).

4. Sims, J. R., Crump, J. E. and Lee, B. Y. S., "Research Studies of Metallized, Fuel-Rich Propellants," AIAA Second Propulsion Joint Specialist Conference, Preprint No. 66-616 (1966).

5. Glassman, I., et al "Vapor-phase Diffusion Flames in the Combustion of Magnesium and Aluminum: I, II and III," AIAA Progress in Astronautics and Aeronautics: Heterogeneous Combustion, (Academic Press, N. Y., 1964), Vol. 15, pp. 75-176.

6. Maček, A., Friedman, R. and Semple, J. M., "Techniques for the Study of Combustion of Beryllium and Aluminum Particles," AIAA Progress in Astronautics and Aeronautics: Heterogeneous Combustion, (Academic Press, N. Y., 1964), Vol. 15, pp. 3-16.

7. Lipson, S., "Cellular Aluminum for Energy Dissipation Systems," NASA CR-93, Metallurgy Research Laboratory, Frankford Arsenal, Philadelphia, Pa. (1964).

8. Scheidegger, A. E., Physics of Flow through Porous Media (Macmillan Co., London, 1960).

9. Sutherland, G., "Investigation of Hybrid Propellant Combustion," Final report for Contract N 123 (60530) 32335 A (FBM), Rocket Research Corporation, March 25, 1964 (CONFIDENTIAL).

10. Eisel, J. L., Horton, M. D., Price, E. W. and Rice, D. W., "Preferred Frequency Oscillatory Combustion of Solid Propellants," American Institute of Aeronautics and Astronautics Journal, 2, 7, 1319 -1323 (1964).

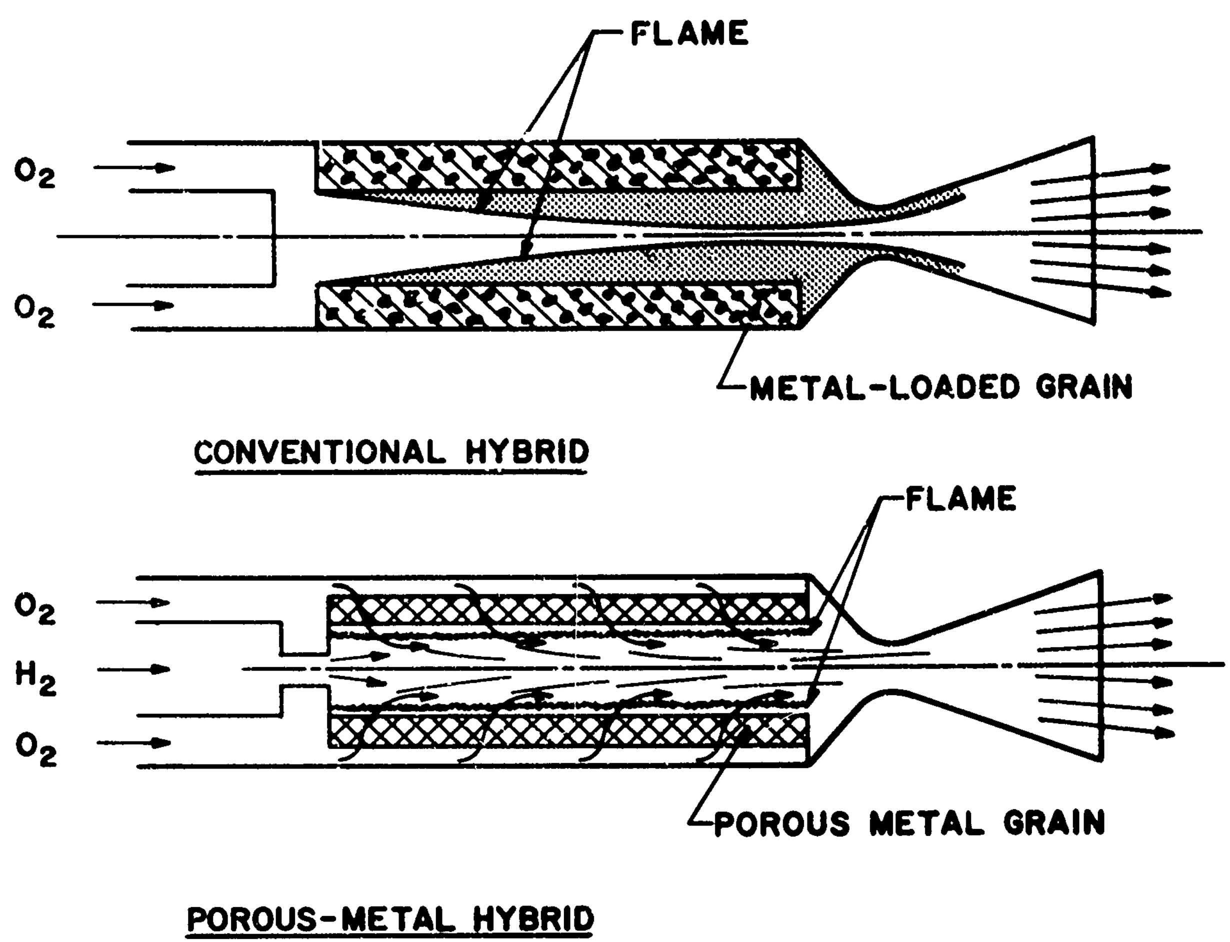


FIG. 1 SCHEMATIC COMPARISON OF POROUS-METAL AND CONVENTIONAL HYBRID ROCKET MOTORS

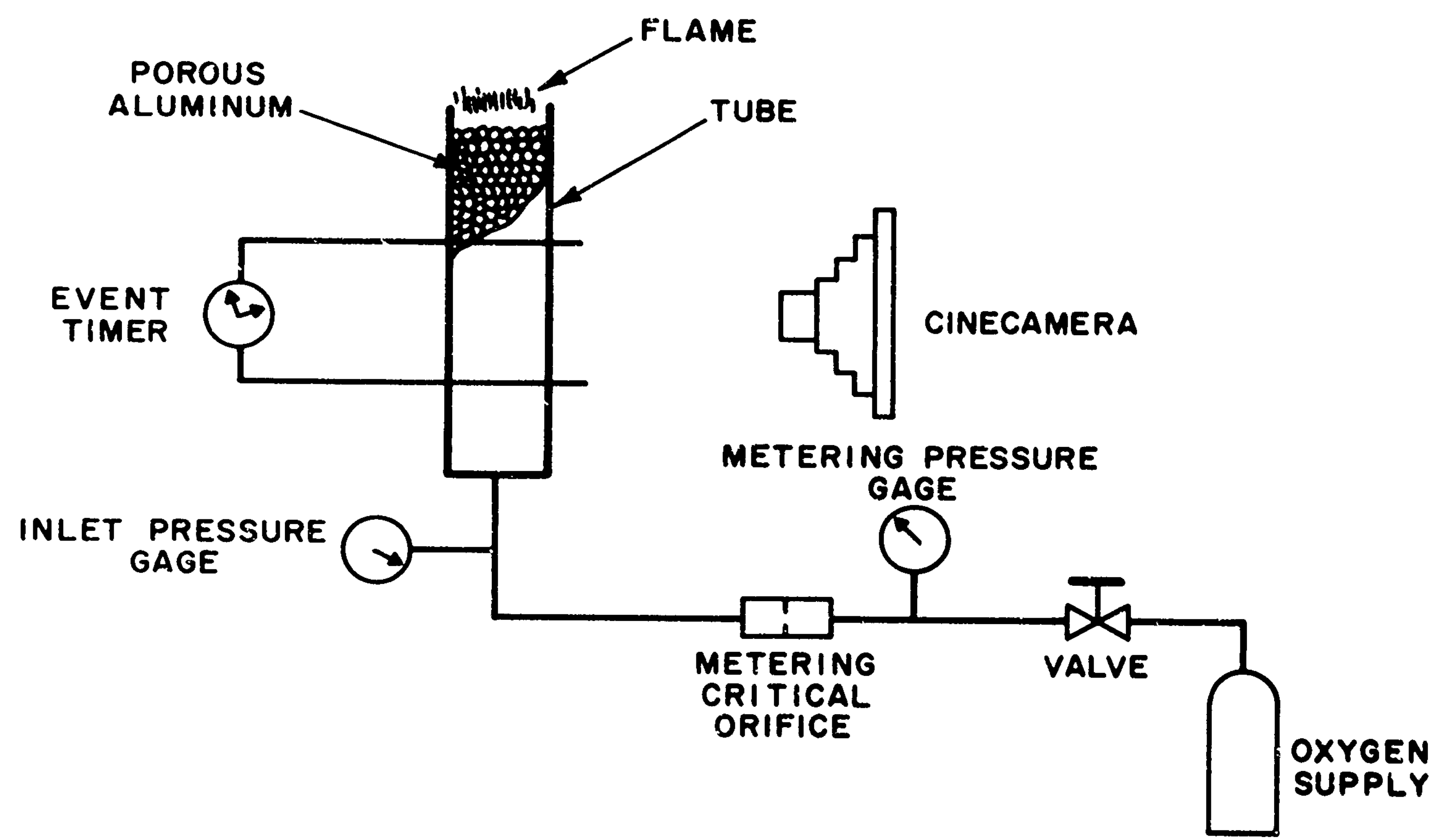
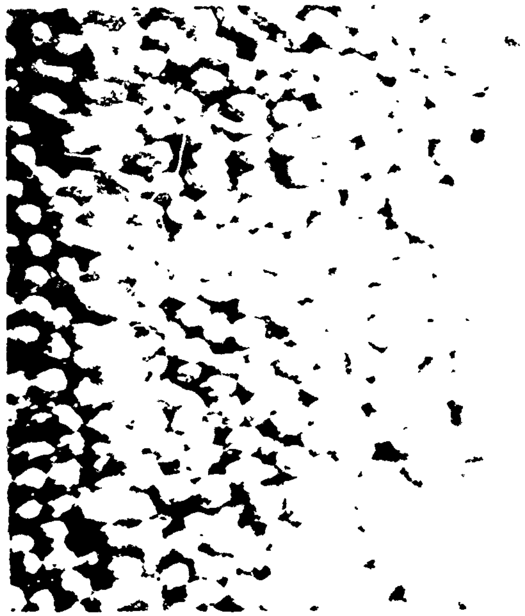


FIG.2 SCHEMATIC REPRESENTATION OF EXPERIMENTAL OPERATION



BONDED POWDER
(125μ SPHERES)

COMPRESSED "WOOL"
(20μ FIBERS)

CELLULAR MESH
(150μ CELLS)

FIG. 3 PHOTOMICROGRAPHS OF ALUMINUM POROUS-PLUG STRUCTURES TESTED

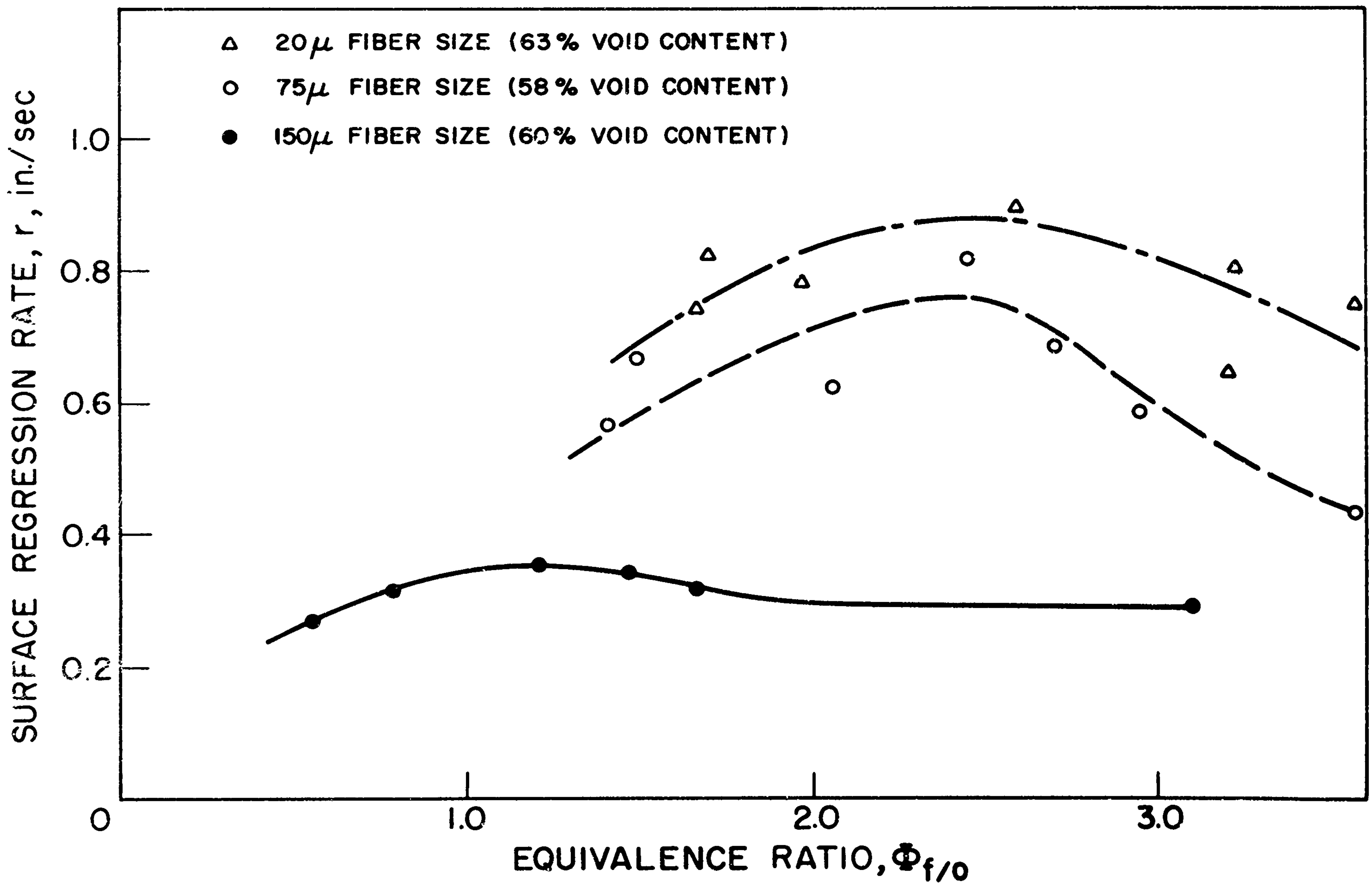


FIG.4 DEPENDENCE OF ALUMINUM "WOOL" SURFACE REGRESSION RATE ON Aℓ-O_2 EQUIVALENCE RATIO FOR THREE FIBER SIZES

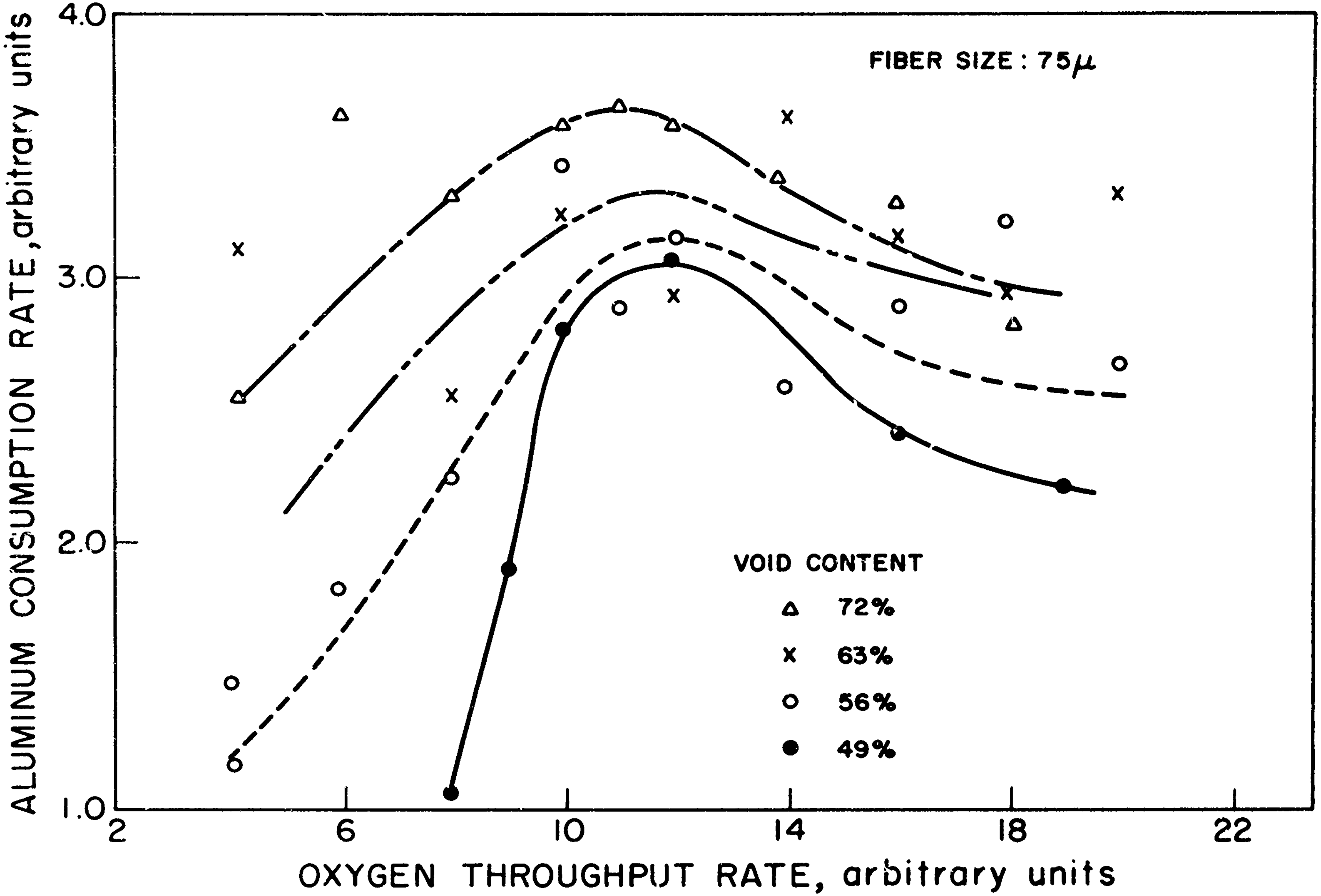


FIG.5 DEPENDENCE OF ALUMINUM "WOOL" MASS CONSUMPTION RATE ON OXYGEN THROUGHPUT RATE FOR FOUR VOID CONTENTS

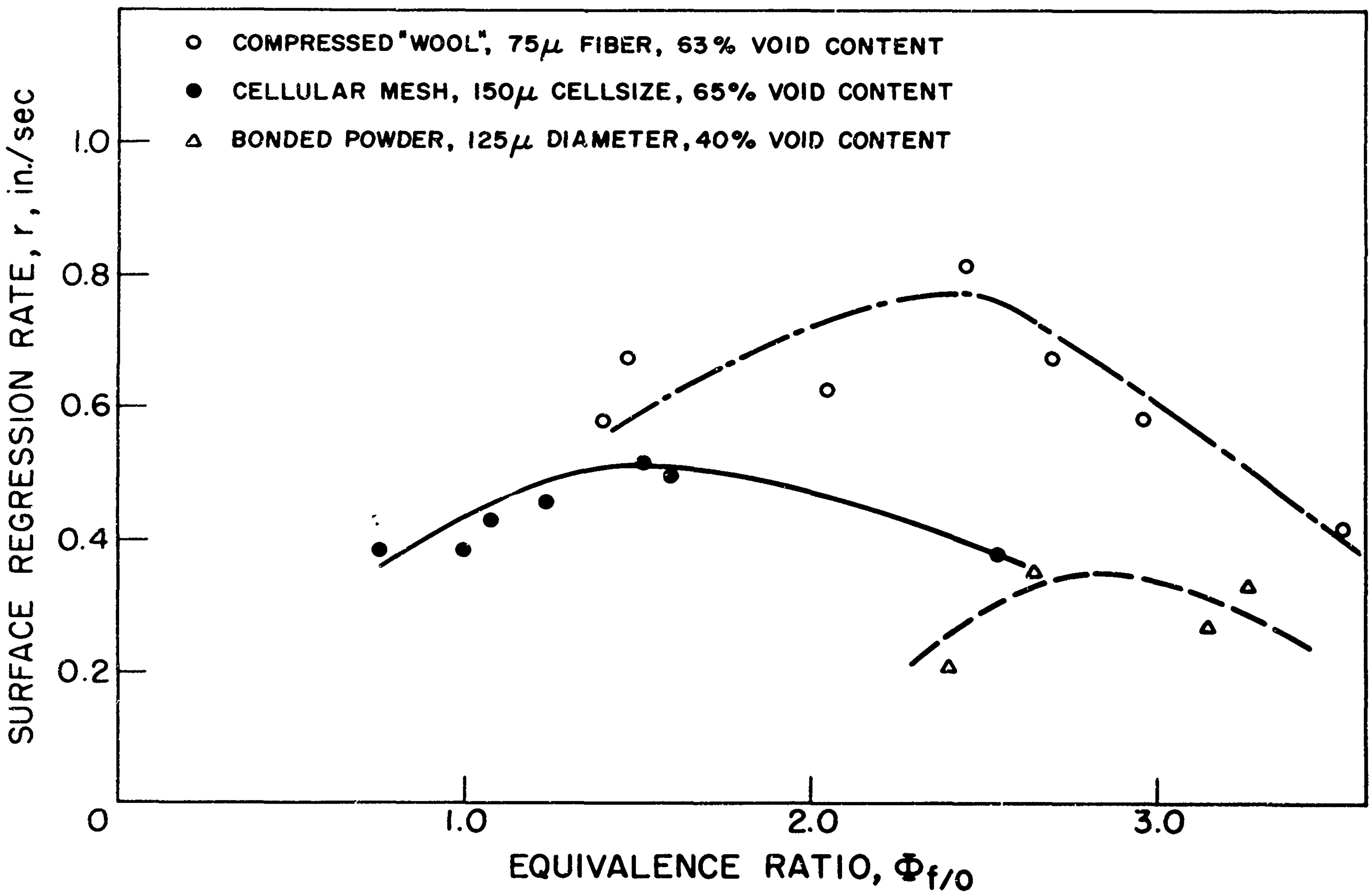


FIG. 6 DEPENDENCE OF SURFACE REGRESSION RATE ON $A\ell$-O_2 EQUIVALENCE RATIO FOR THREE TYPES OF POROUS PLUGS

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13 ABSTRACT

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Porous Plug						
Aluminum						
Hybrid Combustion						

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