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DEVELOPMENT AND EVALUATION OF HIGH-TEMPERATURE TUNGSTEN ALLOYS

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ABSTRACT

High-tungsten alloys were prepared by powder metallurgy techniques. Excellent strength and ductility at room temperature were found in the W-Ni-Mo-Ru system and in W-Ni-Fe alloys containing platinum and/or ruthenium. The effects of prolonged annealing at 1600°F on room-temperature properties were studied; W-Ni-Fe-Pt-Ru alloys were least affected by this treatment. Oxidation rates for most alloys at 2000°F were 2 to 4 times that of unalloyed tungsten; an exception was a W-Ni-Mo-Ru alloy which oxidized at 1/5 the rate of tungsten. Slip casting techniques and induction-sintering of loosely compacted powders were used to produce compacts of W-Ni-Fe materials having section thicknesses of 1 to 2 inches.

DEVELOPMENT AND EVALUATION OF HIGH-TEMPERATURE TUNGSTEN ALLOYS

I. INTRODUCTION

This progress report covers the period April 1, 1960, to June 30, 1960, summarizing work performed on ARF Project 2158, "Development and Evaluation of High-Temperature Tungsten Alloys" (title unclassified).

Powder metallurgy techniques have been used to prepare high-tungsten alloys which exhibit good room-temperature ductility and are capable of operation at 2000° F. Earlier studies under this program have shown that W-Ni-Fe-Ru alloys possess higher strength up to 2000° F than other materials under investigation. A severe loss of room-temperature ductility, however, has been observed in some alloy systems following lengthy annealing treatments at 1600° F. Efforts have been made during this reporting interval to improve the thermal stability of W-Ni-Fe-Ru compositions by further alloying.

Fabricability of these tungsten-base alloys is an important consideration. The feasibility of producing large and complex shapes has been the subject of a large portion of recent experimental work. Techniques for metal powder consolidation, sintering, and joining have been investigated in order to increase the size of the sintered compacts under study.

Most of the alloys developed under this program exhibit poor oxidation resistance at temperatures up to 2000° F; in some cases, oxidation rates are four times that of unalloyed tungsten. Recent studies have shown that substantial improvements may be made by alloying. Fused coatings of a nickel-chromium base alloy have protected the W-Ni-Fe material for 500 hours in static air at 2000° F and for 190 hours at 2100° F. Coating failures have occurred at edges or sharp corners, and recent improvements in coating techniques are expected to extend the useful life of the coated specimens.

During the current quarterly period, major emphasis has been shifted from alloy development to the study of processing techniques. A number of promising new compositions were prepared and evaluated at room temperature. Some elevated temperature testing remains to be completed before the alloy development phase is concluded.

Property data presented in the following sections were obtained from specimens prepared by cold pressing followed by liquid-phase sintering, unless otherwise specified.

II. DISCUSSION OF RESULTS

A. Alloy Development

Previous work on ductile tungsten-base alloys with an envelope-type structure has demonstrated that improvements should be made in several areas including impact strength, elevated temperature stress-rupture properties, oxidation resistance, and thermal stability. The compositions currently under study were prepared in order to effect improvements in one or more of these properties. Test data for these alloys are presented in Table I; elevated-temperature properties for some of the more promising materials are currently being evaluated, and will be included in a subsequent report.

1. W-Ni-Fe Alloys

Several ternary W-Ni-Fe compositions were prepared to study the effects of large tungsten particle sizes in alloys containing 90 to 92.5 wt% tungsten. The tungsten was added as a very coarse powder to increase the density of slip-cast compacts prior to sintering, or to raise the apparent density of loosely filled powders for induction sintering of large parts. Test data in Table I show that excellent ductility is maintained up to the 92.5 wt% tungsten level in compacts containing 10 micron tungsten powder. Most compositions studied under this program contained tungsten having a 3 micron average particle size; the transverse-rupture strength of a 90W-6Ni-4Fe* alloy containing the finer tungsten was 260,000 psi. Some of these compositions were used in slip-casting and induction heating experiments, which are described in subsequent sections of this report.

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* Compositions are reported in weight per cent.

TABLE I

ROOM-TEMPERATURE PROPERTIES OF TUNGSTEN-BASE ALLOYS

Composition (wt%)[a]	Transverse Rupture Strength (psi)	Deflection (in.)[b]	Hardness VPN(10Kg)
90W-6Ni-4Fe[c]	249,000	0.6+[d]	309
90W-6Ni-4Fe[e]	259,000	0.6+[d]	299
92.5W-4.5Ni-3Fe[e]	259,000	0.6+[d]	
90W-5.1Ni-3.9Fe-1 AMS 4775[f]	256,000	0.6+[d]	
90W-4.2Ni-3.8Fe-2 AMS 4775[f]	258,000	0.6+[d]	312
90W-2.4Ni-3.6Fe-4 AMS 4775[f]	272,000	0.41	314
90W-3.2Fe-6.8 AMS 4775[f]	261,000	0.26	309
85W-5Fe-10 AMS 4775[f]		sample blistered	
90W-4.8Ni-3.2Fe-2Pt	263,000	0.6+[d]	289
90W-3.6Ni-2.4Fe-4Pt	265,000	0.43	325
90W-9Ni-1Ru	260,000	0.18	351
90W-8.1Ni-0.9Fe-1Ru	300,000	0.45	341
90W-7.2Ni-1.8Fe-1Ru	296,000	0.6+[d]	345
90W-6.3Ni-2.7Fe-1Ru	296,000	0.6+[d]	330
90W-5.4Ni-3.6Fe-1Ru	297,000	0.48	333
90W-4.5Ni-4.5Fe-1Ru	297,000	0.30	342
90W-5.85Ni-3.9Fe-0.25Si	245,000	0.28	292
90W-5.7Ni-3.8Fe-0.5Si	218,000	0.19	289
90W-5.4Ni-3.6Fe-1Si	190,000	0.17	286
90W-6Ni-2.5Fe-0.75Pt-0.75Ru	324,000	0.6+[d]	327
90W-5.6Ni-2.4Fe-1Pt-1Ru	338,000	0.60	346
90W-4.9Ni-2.1Fe-2Pt-1Ru	329,000	0.32	353

TABLE I (continued)

Composition (wt%)[a]	Transverse Rupture Strength (psi)	Deflection (in.)[b]	Hardness VPN(10Kg)
90W-5Ni-2Fe-1.5Pt-1.5Ru	348,000	0.33	388
90W-8.5Ni-0.5Mo-1Ru	204,000	0.08	336
90W-7.5Ni-1.5Mo-1Ru	286,000	0.18	338
90W-6.5Ni-2.5Mo-1Ru	345,000	0.40	348
90W-5.5Ni-3.5Mo-1Ru	240,000	0.09	351
90W-6Ni-2.5Mo-0.75Pt-0.75Ru	295,000	0.18	346

a. Cold pressed specimens containing 3 micron tungsten powder, unless otherwise specified.
b. Span length 1.25 in.; specimens 1/8 in. thick.
c. Tungsten powder 7 micron average particle size.
d. Test specimen did not break after 1.5 t bend.
e. Tungsten powder 10 micron average particle size.
f. AMS 4775 contains 13.5% Cr, 4.5% Fe, 4.5% Si, 3.5% B, 0.8% C, balance Ni.

2. W-Ni-Fe-AMS 4775 Alloys

The excellent oxidation resistance of fused AMS 4775 coatings on sintered W-Ni-Fe compacts suggested that this alloy may be incorporated into the matrix of W-Ni-Fe materials prior to sintering, with a resultant increase in oxidation resistance of the composite. A series of alloys was prepared using AMS 4775 powders in amounts ranging from 1 to 10 wt%; these compositions are essentially W-Ni-Fe-Cr with smaller amounts of boron and silicon. The oxidation test results, reported in a subsequent section, showed little improvement over the W-Ni-Fe base. However, the room-temperature properties (Table I) indicate good strength and workability up to 4 wt% AMS 4775, and good strength with somewhat reduced ductility in the alloy containing 6.8 wt% of AMS 4775.

3. W-Ni-Fe-Pt Alloys

Platinum was added to a 90 wt% W-Ni-Fe base at levels of 2 and 4 wt%. The high melting point and good oxidation resistance of platinum were expected to improve the elevated-temperature strength and oxidation resistance of the composite. Table I shows that excellent room-temperature strength and ductility were obtained in both alloys; elevated-temperature tensile test results will be presented in a subsequent report. A moderate improvement in oxidation resistance was noted at 2000°F. The relatively high (~ 5 wt%) solubility of platinum in tungsten is accompanied by a hardness increase to about VPN 900 in the binary system. A very small hardness rise occurred in the W-Ni-Fe-Pt materials, indicating reduced solubility of platinum in tungsten in the quaternary alloys.

4. W-Ni-Fe-Ru Alloys

Previous studies have shown that the addition of ruthenium to the W-Ni-Fe base results in greatly increased strength at temperatures up to 2000°F. A series of W-Ni-Fe-Ru alloys were investigated at the 1 wt% Ru level; nickel-to-iron ratios were varied from 9:1 to equal parts, and a W-Ni-Ru ternary composition was also included. Table I shows that excellent room-temperature strength was obtained in all quaternary materials and that maximum ductility was found in alloys having nickel-iron ratios of 8:2 and 7:3. The addition of 1 wt% ruthenium to the W-Ni-Fe base produced an increase of about 40, 000 psi in transverse-rupture strength, and the high ductility was maintained. These alloys, however, exhibit substantial hardness increases upon annealing at 1600°F, and the effects of further alloying upon thermal stability are discussed in a subsequent section.

5. W-Ni-Fe-Si Alloys

Silicon was added to a 90W-Ni-Fe base in amounts of 0. 25, 0. 5, and 1 wt%. Increasing quantities of silicon caused a marked decrease in both strength and ductility, as noted in Table I. In addition, hardness levels were slightly lower, although these values may have been affected by the presence of fine porosity in the specimens. The oxidation resistance was moderately increased by the silicon additions.

6. W-Ni-Fe-Pt-Ru Alloys

The addition of small quantities of platinum and ruthenium to a 90W-Ni-Fe base resulted in the best combination of room-temperature strength and ductility developed to date. Table I shows that the 90W-6Ni-2. 5Fe-0. 75Pt-0. 75Ru composition had a transverse-rupture strength of 324, 000 psi, a value some 64, 000 psi higher than the 90W-6Ni-4Fe material; the excellent ductility of the ternary base was preserved. Figure 1 illustrates the fine grain size and good matrix distribution in the W-Ni-Fe-Pt-Ru alloy. Higher strength with slightly reduced ductility was found in the alloy containing 1 wt% each of platinum and ruthenium. The thermal stability in this system was found to be very good at 1600°F; oxidation resistance at 2000°F was moderately better than the 90W-Ni-Fe base.

7. W-Ni-Mo-Ru Alloys

Four compositions in the W-Ni-Mo-Ru system were studied; the ruthenium content was maintained at 1 wt%, and the nickel and molybdenum levels were varied. One alloy, 90W-6. 5Ni-2. 5Mo-1Ru, had exceptional room-temperature strength and ductility -- the transverse-rupture strength of 345, 000 psi was 85, 000 psi higher than the 90W-6Ni-4Fe material; the deflection of 0. 4 inch indicates very good room-temperature workability. The oxidation resistance of the W-Ni-Mo-Ru alloy was about five times that of unalloyed tungsten, and some twenty times that of 90W-6Ni-4Fe at 2000°F.

A substantial hardness increase occurred upon annealing at 1600°F, indicating a lack of thermal stability. More detailed discussions of oxidation resistance and thermal stability of the materials under study are included in subsequent sections of this report.

B. Thermal Stability

Many of the alloys under study exhibit a precipitate in the matrix after prolonged annealing at temperatures in the range of 1400 to 1700°F. The precipitate is usually accompanied by a hardness increase which causes a reduction of room-temperature ductility. Earlier studies showed that alloys of the W-Ni-Cr and W-Ni-Fe systems are relatively unaffected by these annealing treatments, whereas W-Ni-Co and W-Ni-Fe-(Co, Ru) are embrittled. Efforts have been devoted to further complexing in the W-Ni-Fe-Ru system in order to improve the thermal stability of these highly promising materials.

Table II presents the results of hardness tests on some of the recently developed tungsten-base alloys; hardness values are reported for the as-sintered condition and for specimens which were annealed for 250 hours at 1600°F. Very slight hardness increases occurred in the W-Ni-Fe-Pt and the W-Ni-Fe-Pt-Ru systems whereas larger hardness rises occurred in the W-Ni-Ru, W-Ni-Fe-Ru, and W-Ni-Mo-Ru systems. The extent of the matrix phase precipitates in the 90W-9Ni-1Ru alloy is illustrated in Figure 2. Prior to annealing, this specimen had a microstructure which resembled that shown in Figure 1.

Thermal stability was also studied at annealing temperatures below 1600°F. Specimens of several alloys were annealed for 100 hours at 700, 900, 1100, and 1300°F. These heat treatments produced no hardness increases in 90W-6Ni-4Fe and 90W-4.2Ni-2.8Fe-3Cr materials, and slight hardness rises occurred at 1300°F in the 90W-3Ni-2Fe-5Mo and 90W-5.4Ni-3.6Fe-1Ru compositions. The critical temperature range for most compositions appears to lie between 1300 and 1700°F, although other temperatures will be investigated for the most promising alloys developed to date.

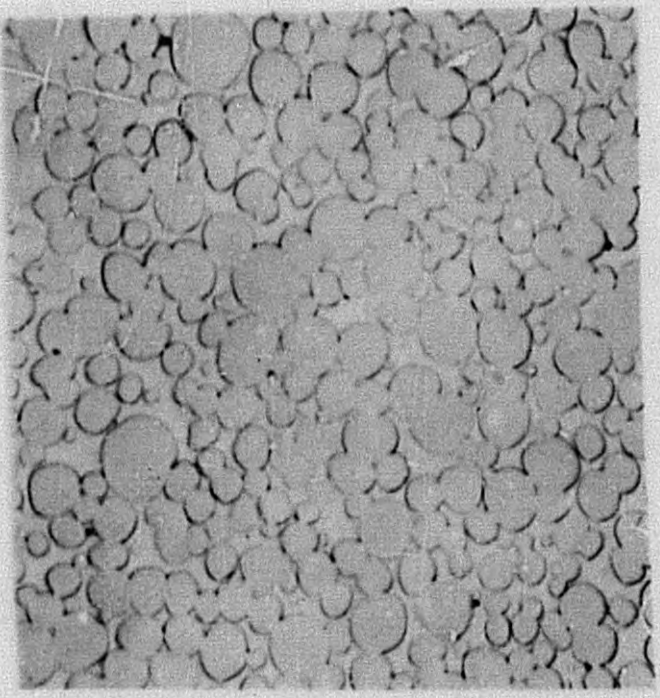

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Fig. 1

90W-6Ni-2.5Fe-0.75Pt-0.75Ru alloy. As-sintered structure, showing the relatively fine grain size typical of compositions containing ruthenium. Unetched.

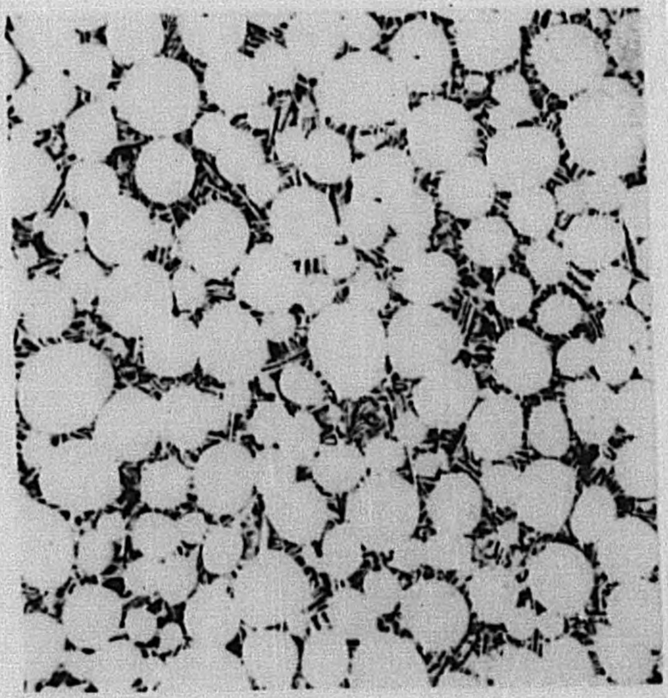

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Fig. 2

90W-9Ni-1Ru alloy, annealed for 250 hours at 1600° F. The matrix-phase precipitate was accompanied by a large hardness increase at room temperature.

Etchant: HNO_3 + HF + glycerine.

TABLE II

ROOM-TEMPERATURE HARDNESS OF TUNGSTEN-BASE ALLOYS

	Hardness, VPN(10kg)		
Composition (wt%)	As Sintered	Annealed 1600°F - 250 hrs	Hardness Change
90W-4.8Ni-3.2Fe-2Pt	289	319	+30
90W-3.6Ni-2.4Fe-4Pt	325	345	+20
90W-9Ni-1Ru	351	508	+157
90W-8.1Ni-0.9Fe-1Ru	341	417	+76
90W-7.2Ni-1.8Fe-1Ru	345	421	+76
90W-5.6Ni-2.4Fe-1Pt-1Ru	346	360	+14
90W-4.9Ni-2.1Fe-2Pt-1Ru	353	401	+48
90W-5Ni-2Fe-1.5Pt-1.5Ru	388	409	+21
90W-7.5Ni-1.5Mo-1Ru	338	493	+155
90W-6.5Ni-2.5Mo-1Ru	348	488	+140
90W-6Ni-2.5Mo-.75Pt-.75Ru	346	491	+145

C. Oxidation Resistance

Oxidation tests were conducted at 2000°F on a number of recently developed alloys. The results of these tests are presented in Table III; data for the 90W-6Ni-4Fe material and also unalloyed tungsten are included for comparison. Table III shows that the oxidation resistance of the W-Ni-Fe base is moderately improved by the additions of AMS 4775, silicon, platinum, and platinum-ruthenium. The addition of 1 wt% each of molybdenum and ruthenium to the W-Ni-Fe base produced a substantial increase in oxidation resistance, the metal loss of 0.012 inch/hr approaching that of pure tungsten (0.008 inch/hr). Greatly improved oxidation resistance was noted in the 90W-6.5Ni-2.5Mo-1Ru alloy; the metal loss of 0.0014 inch/hr was over five times less than the value for unalloyed tungsten. Previous work has shown that molybdenum additions to the W-Ni-Fe base promote oxidation resistance. The mechanism of oxidation in these materials had not been fully investigated, and further study may lead to additional improvements in oxidation resistance by alloying.

D. Oxidation Protection

The effectiveness of fused AMS 4775 coatings in protecting W-Ni-Fe alloys at 2000° F has been demonstrated. More recent tests at 2100°F show that these coatings afford good protection for 190 hours. The failure occurred at a sharp corner of the test specimen where the coating thickness was insufficient; the remainder of the sample showed little attack of the base metal. These results indicate that elimination of sharp edges or corners should greatly increase the life of the AMS 4775 coatings on W-Ni-Fe materials. Additional test specimens have been prepared from tungsten-base alloys containing molybdenum and ruthenium.

E. Processing Techniques

Major efforts during the current reporting interval have been devoted to increasing the size and section thickness of the sintered materials. Slip casting, induction sintering of loosely compacted powders, and resistance welding techniques are under investigation.

TABLE III

OXIDATION TEST DATA FOR TUNGSTEN-BASE ALLOYS AT 2000°F

Composition (wt%)	Metal Loss (0.001 in./hr)[a]
90W-6Ni-4Fe	34
90W-4.2Ni-3.8Fe-2 AMS 4775[b]	25
90W-2.4Ni-3.6Fe-4 AMS 4775[b]	24
90W-3.2Fe-6.8 AMS 4775[b]	25
90W-3.6Ni-2.4Fe-4Pt	23
90W-5.85Ni-3.9Fe-0.25 Si	21
90W-5.7Ni-3.8Fe-0.5Si	20
90W-5.4Ni-3.6Fe-1Si	16
90W-4.8Ni-3.2Fe-1Mo-1Ru	12
90W-6Ni-2.5Fe-0.75Pt-0.75Ru	21
90W-5.6Ni-2.4Fe-1Pt-1Ru	27
90W-6.5Ni-2.5Mo-1Ru	1.4
Unalloyed W	8

a. Average loss per exposed surface.
b. AMS 4775 contains 13.5% Cr, 4.5% Fe, 4.5% Si, 3.5% B, 0.8% C, balance Ni.

1. Slip Casting

Experiments have been conducted to determine the effects of tungsten particle size on the as-cast density of W-Ni-Fe compacts. The objective of these studies is to obtain the greatest possible density in the slip-cast compacts in order to reduce shrinkage and distortion during sintering. Varying amounts of the collodion binder were used in an effort to minimize the settling out of the heavier tungsten particles in the slurry. Good strength and ductility were obtained on sintered specimens of slip-cast 92.5W-4.5Ni-3Fe alloy containing 10 micron tungsten powder. Shrinkage during sintering was 20 per cent compared to the 25 per cent linear shrinkage for the alloy containing 3 micron tungsten powder. Thicker specimens will be cast to determine whether or not the components segregate prior to solidification in the plaster molds. A large slip-cast ingot of 95W-3Ni-2Fe has been sintered. This specimen is 3 inches long, 1 1/4 inch wide, 7/8 inch thick, and weighs 2 pounds; a polished surface exhibits a satisfactory microstructure.

2. Induction Sintering

Loosely-compacted W-Ni-Fe powders have been sintered using a moving hot zone technique. The apparatus, shown in Figure 3, consists of an alumina crucible and a metal powder feed mechanism which are contained under an atmosphere of $90N_2$-$10H_2$. A charge of about 300 grams is placed in the bottom of the crucible and sintered for 3/4 hours at 2650°F. Additional powder is added to the top of the ingot, and the induction coil is moved upward to sinter the new charge. This process is continuous, with only the top portion of the ingot containing liquid phase. The first large ingot was made from 85W-10.5Ni-4.5Fe material containing 20 micron tungsten powder. The high matrix volume was used to insure that the ingot would completely fill the mold, and the coarse tungsten powder was used to obtain good flow characteristics for the powder feed device. The sintered ingot, weighing over 3000 grams, contained some porous areas and was extremely coarse grained; Figure 4 illustrates the large grain size. The sintering apparatus has been modified so that finer tungsten powders can be used. Subsequent experiments will be conducted on compositions containing 87.5 and 90 wt% tungsten.

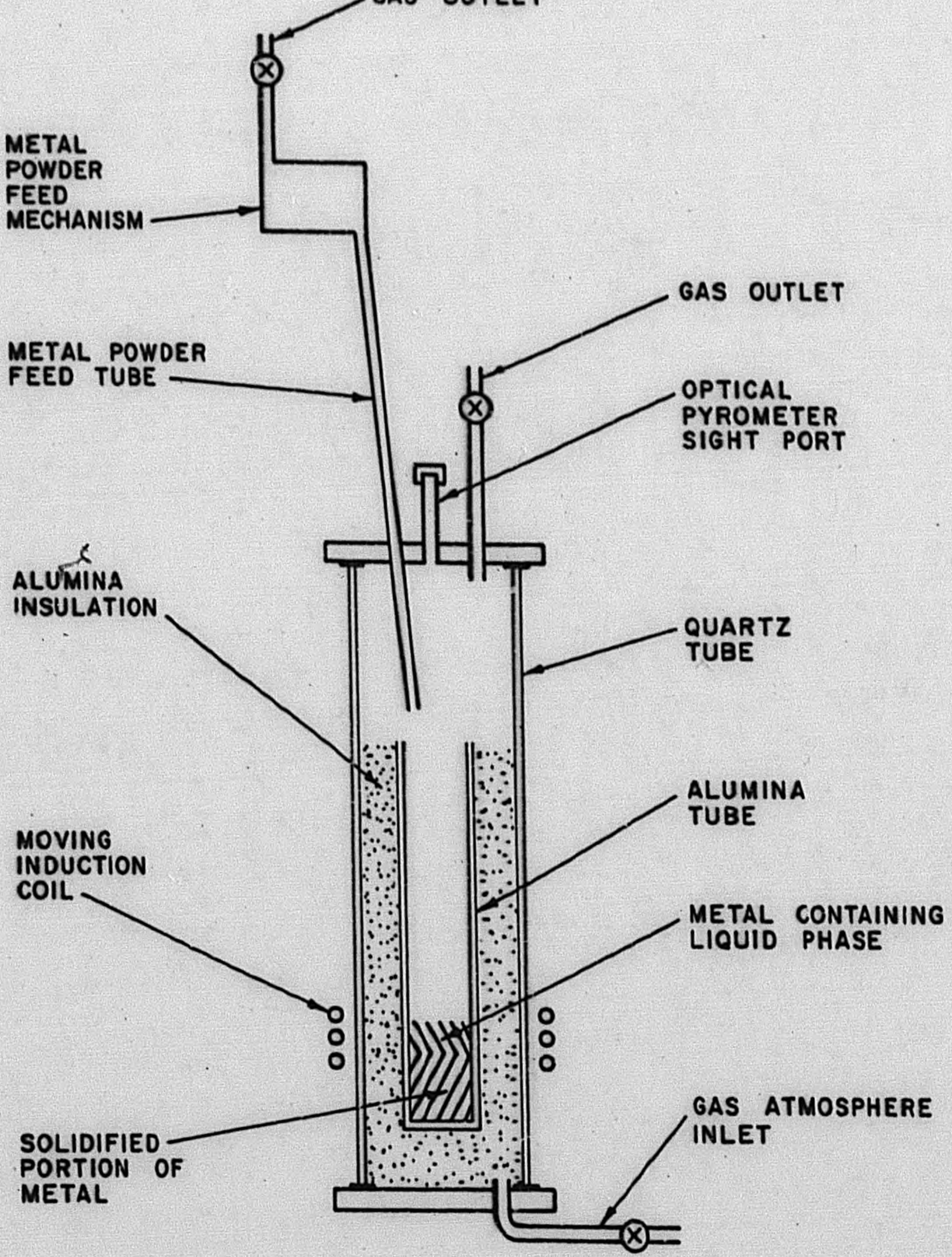

FIG. 3 - APPARATUS USED FOR MOVING-HOT-ZONE SINTERING OF TUNGSTEN-BASE ALLOYS.

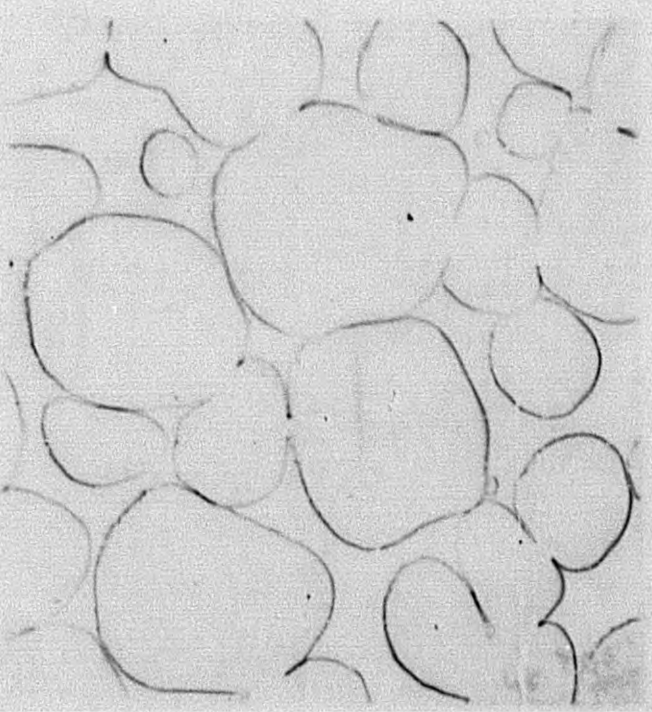

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Fig. 4

85W-10.5Ni-4.5Fe alloy made from 20 micron tungsten powder, sintered using the moving hot-zone technique. The excessively large grain size is due in part to the coarse tungsten powder used.

3. Joining

Previous studies have shown that sintered W-Ni-Fe materials may be satisfactorily joined by heating the area of contact to a temperature above the melting point of the matrix phase. Joints made by induction heating under a reducing atmosphere were as strong as the parent metal. Initial spot welding experiments on rolled W-Ni-Fe sheet showed that bonding was not as satisfactory as the induction heating method, probably because the welding time was not sufficient to permit diffusion and growth of the tungsten grains in the joint. Recent efforts using resistance welding techniques have involved the joining of sintered bars having a cross-section of 3/16 inch by 1/2 inch. A number of joints have been made and some of the microstructures show a satisfactory bond, although a moderate hardness increase was noted in the heat-affected area. Some squeezeout of the matrix phase occurred at the edges of the welded area; the amount of matrix loss appeared to be too small to account for the hardness increase in the specimens. Stress-relief annealing may be required to reduce the hardness in the heat-affected area. Additional samples will be joined and stress-relieved, followed by tensile tests of the welds. Specimens having greater section thickness will also be joined.

III. SUMMARY

Powder metallurgy techniques were used to prepare high-tungsten alloys. Several ternary W-Ni-Fe compositions containing relatively coarse (10 micron) tungsten powder were found to be as strong and ductile as similar alloys made with the finer 3 micron powder. A nickel-chromium base alloy, AMS 4775, was added to the matrix phase of 90W-Ni-Fe materials. Although no significant improvements in oxidation resistance of the composites were noted, the alloys possessed good strength and ductility at room temperature. The addition of 2 and 4 wt% platinum to the 90W-Ni-Fe base did not impair the strength and workability, and some improvement in oxidation resistance was noted. A series of 90W-Ni-Fe-1Ru compositions was prepared using varying nickel and iron contents; maximum strength and ductility were found at nickel-iron ratios of 8:2 and 7:3. Silicon additions to the 90W-Ni-Fe base caused a decrease in room-temperature strength and ductility, and a moderate increase in oxidation resistance. Exceptionally good room-temperature

strength and ductility were found in W-Ni-Fe-Pt-Ru compositions. One composition containing 0.75 wt% each of platinum and ruthenium had a transverse-rupture strength of 324,000 psi compared to 260,000 psi for the 90W-6Ni-4Fe alloy; the excellent ductility of the ternary base was maintained. Several W-Ni-Mo-Ru compositions were studied. One alloy, 90W-6.5Ni-2.5Mo-1Ru, had a transverse-rupture strength of 345,000 psi with excellent room-temperature ductility.

The thermal stability of these tungsten-base alloys was investigated by annealing specimens for 250 hours at 1600°F. This treatment produced a precipitate in the matrix phase of some alloys which resulted in increased hardness and lower ductility at room temperature. Of the compositions currently under study, W-Ni-Fe-Pt and W-Ni-Fe-Pt-Ru exhibited good thermal stability, whereas large hardness increases were shown by W-Ni-Fe-Ru and W-Ni-Mo-Ru.

Oxidation tests at 2000°F showed that most of the alloys under study oxidized at lower rates than 90W-6Ni-4Fe but were inferior to unalloyed tungsten. One exception was noted: the oxidation resistance of the 90W-6.5Ni-2.5Mo-1Ru material was about five times superior to that of pure tungsten. Oxidation protection of a 90W-6Ni-4Fe alloy by a fused coating of a nickel-chromium base alloy, AMS 4775, was effective for 190 hours in air at 2100°F. Failure occurred at a sharp corner, indicating that larger radii are required for the formation of an adequate coating thickness at edges and corners.

Major efforts were devoted to studies of fabricating techniques including metal powder consolidation, sintering, and joining methods. Slip-casting in plaster molds, using W-Ni-Fe powders containing coarse (10 micron) tungsten powder, yielded a satisfactory product which exhibited reduced shrinkage compared to material made with 3 micron tungsten. Induction sintering of loosely compacted 85W-Ni-Fe powders was accomplished using a moving hot zone technique. The metal powders were continuously fed into the top of the ingot which was maintained at liquid-phase sintering temperature. Resistance welding of sintered 90W-6Ni-4Fe bars, 3/16 inch thick, showed promise on the basis of initial results. A moderate hardness increase occurred in the molten zone, and some of the matrix phase squeezed out.

IV. FUTURE WORK

Elevated-temperature tests will be conducted on the most promising compositions developed to date. The alloys to be tested include the W-Ni-Fe-Pt-Ru and the W-Ni-Mo-Ru systems. Tensile strength, elongation, and stress-rupture life will be evaluated at 2000° F, and some data will be obtained at 1600° F.. Thermal stability studies will include room-temperature transverse-rupture tests of specimens annealed for 250 hours at 1600° F. The more promising alloys containing molybdenum, platinum, and ruthenium have been coated with AMS 4775, and the specimens are being tested in air at 2000° F.

Major efforts during the subsequent period will be devoted to studies of processing techniques. Slip casting will be used to prepare compacts of alloys containing platinum and ruthenium, and large specimens will be prepared to study segregation, distortion, and other variables. Induction heating experiments, using the moving hot zone technique, will be continued. Initially, ternary W-Ni-Fe alloys will be sintered; the objectives will be to increase tungsten levels to at least 90 wt% and to reduce the tungsten particle size in the sintered ingots. Resistance welding studies will be continued on W-Ni-Fe alloys. When satisfactory techniques have been developed, section sizes will be increased, and some of the more promising alloys will be joined.

V. LOGBOOKS AND CONTRIBUTING PERSONNEL

Data for this report are recorded in ARF Logbooks C-9141, -1143, -9403, -9425, -9755, -8488, -8489, -8490, -8491, -8492, -8553, -8554, -8885, -8886, and -9113.

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The following personnel have been the principal contributors to the planning and execution of this work:

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Respectfully submitted,

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