tation Center, DDC has accepted the challenge by launching both a long-range and short-range improvement program, one aspect of which has been described in this paper.

BIBLIOGRAPHY

(1) A. Jacobius, *Aerospace Med.* **30**, 507 (1959).
(2) "Coordination of Information on Current Scientific Research and Development Supported by the U. S. Government," Committee on Government Operations, U. S. Senate, Report No. 263, 1961.
(3) W. A. Barden, W. Hammond, and J. H. Heald, "Automation of ASTIA—A Preliminary Report," Armed Services Technical Information Agency, AD 227 000, 1959.
(4) W. Hammond, and Associates, "Controlling Literature by Automation," Armed Services Technical Information Agency, AD 247 000, 1960.
(5) E. Wall, Final Report—First Revision of the *Thesaurus of ASTIA Descriptors*. Armed Services Technical Information Agency, AD 278 168, 1962.
(6) J. F. Caponio, and T. L. Gillum, "Practical Aspects Concerning the Development and Use of ASTIA's Thesaurus in Information Retrieval," Presented at a meeting of the Division of Chemical Literature, 142nd National Meeting of the American Chemical Society, September, 1962.

Literature Research for a Space Materials Research Program*

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Ballistic and skip glide reentry as well as solid propellant propulsion requirements have surpassed the capabilities of the common engineering materials. Extremely high temperature regimes have caused the missile and space systems designer to turn his attention to the relatively unknown refractory materials. A refractory materials applied research and development program was initiated at the Materials Sciences Laboratory of the Aerospace Corporation during 1962. This paper will describe the experiences involved in searching the literature in this field.

The project was initiated by defining the classes of materials of interest; these included the refractory metals, their carbides, borides, oxides, and beryllides. Specific problems within these classes of materials were then singled out to receive a concentrated effort. In order to improve the potential of these materials for operational use in missile and space systems, it was ascertained that improvements must be made towards their development as engineering materials. To accomplish this, programs were outlined with emphasis on the synthesis and fabrication of a well characterized material. The material would then be evaluated for its mechanical and physical properties. The specific properties to be determined are summarized in Table I.

The mechanical and physical properties of any solid material are extremely sensitive to its characterization and method of fabrication. Thus, it is critical that any tabulation of this sort of data be accompanied with the properties of the solid which have been listed within the characterization column. This has been a major disadvantage of many of the tabulations of data, source books, and critical tables, which have been recently published in the materials field. With the direction of the program outlined, attention was turned to a review of the literature.

Table I

Characterization	Mechanical properties	Physical properties
Chemical composition (purity)	Tensile strength	Electrical resistivity
	Compressive strength	Thermal conductivity
Stoichiometry	Modulus of elasticity	Coefficient of linear expansion
Microstructure	Modulus of rupture	Emissivity
Atom structure	Hardness	Melting point
Density (% of theoretical)	Elongation (%)	
	Thermal shock	
Grain size	Poisson's ratio	
Preferred orientation (texture)		

As is generally the case, a materials research group is moderately up-to-date on subjects of personal interest. Within the Metallurgy and Ceramics Group at Aerospace, several of the research scientists had considerable background in the field of refractory materials. This resulted in an immediate collection of papers, reports, books, and reference works.

An initial check was made of the literature generated from the Defense Metals Information Center (DMIC). The materials research scientist has found DMIC to be a valuable assistant in keeping him up-to-date. It is difficult to find suggestions for improvement in its operation with respect to delivering information to where it is important—the user. DMIC has done an excellent job in reviewing the literature over the past two years with respect to all phases of the refractory metals. But what of the other classes of refractory materials mentioned previously? Only one document was related,[1] since they are not within the DMIC charter.

A step in the right direction to amend this deficiency was the creation, last year, of the Ceramics and Graphite Technical Evaluation Section of the AFSC Directorate of Materials and Processes. It has not yet been able to

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generate more than an handful of reports as contrasted to the hundreds from DMIC. It appears that this type of specialized information center can only be efficient when it is operated in conjunction with a group of experimental research scientists who are also doing research in the same area.

Major attention was given to the vast compilation of data recently published by the Armour Research Foundation; namely, the "Handbook of Thermo-Physical Properties of Solid Materials."[2] These volumes were found useful, yet wanting in many respects to the experimental researcher. In what ways was this work lacking? First, the compilation cut-off date was 1957. Unfortunately, in the refractory materials field, this five-year interim period is an extremely critical one, wherein generation of data was increased exponentially. In general, the material for which the physical properties were determined was poorly characterized. The work has been stressed as being "critical" in the sense that all reported values have been included. This is open to criticism since it was discovered that a principal reference pertaining to the melting points of many of the carbides did not appear because the search only went back to 1940. Cited is the work of Agte and Alterthum[3] performed in 1930. This work was still, in 1957, unverified in many respects. Another disadvantage of the Handbook is the collection of the subject index and references in a separate volume. Each volume should have been made selfsufficient in this respect. This shortcoming has been seconded by many other workers in the materials field, and it has been reported that the forthcoming "second edition" of this Handbook, being compiled at the Thermophysical Properties Research Center of Purdue University, will correct this difficulty.

To the research scientist this particular work primarily serves as a partial collection of references between the periods 1940 to 1957. It has concentrated on the thermophysical properties; thus, a search would be required over this same period to retrieve literature describing research in the mechanical properties field.

Among other works published in this field, a significant one is the "Proceedings of the International Symposium on High Temperature Technology" held by the Stanford Research Institute.[4] The chapters within this book were survey articles and were helpful in supplying additional references. A chapter on carbides contained a statement pertaining to the melting point of a mixture of refractory metal carbides. The value exceeded the melting points of the individual carbides (approximately 4000°); if correct, this would be the highest melting point material known. The statement was not referenced, yet it was of extreme interest to a researcher in this field, since it suggested that compound formation may have occurred on mixing the binary carbides. On the other hand, other work had previously shown that the same two carbides were completely soluble within each other. This increase in melting point in a solid solution would be without parallel. This information warranted additional investigation. A personal contact with the author of the chapter revealed that the original manuscript did not contain any references; however, in searching his mind he recalled having seen it in a previous work[5] and had merely restated it. Again, however, it was not referenced. It was finally discovered that the original work was the previously cited reference by Agte and Alterthum which had been neglected by the Armour Handbook. It had been stated over and over, and the reference lost in its restatement. This story is related to show the sort of thing the scientist faces when involved in literature searching. All this happened over a considerable length of time and diverted attention from the primary objective—the performance of experimental research in the laboratory.

Many other books, compendia, and collections of references were also reviewed.[6-13] Again, they all served as additional sources of references. At this point a large number of references had been collected; however, it was intuitively felt that a considerable amount of other literature was still available and unreferenced. It was decided to initiate a more formal and systematic search of the literature, with particular emphasis on the report literature generated under government contracts with the Air Force, Navy, Army, NASA, AEC, and ARPA, and to make use of an American Society for Metals (ASM) Machine Search.

The literature search was requested on the preparation, fabrication, and properties of refractory metals and their alloys, and the refractory carbides, borides, oxides, and beryllides. The search at Aerospace would cover the period 1955–1962, but all basic secondary references going back beyond 1955 would be picked up; the ASM search would go back only to January, 1958.

In response to the request of ASM, approximately 4000 abstracts were received. As might be expected, approximately 60% of these referred to the refractory metals and alloys while the remaining 40% was divided between the borides, carbides, and oxides; only 20 abstracts were found on the beryllides.

In general, the search fell short of expectations. The 4000 references were not well characterized; obviously the machine had simply dropped the cards, which were packaged, and then shipped to the customer. The job of categorizing, of weeding out duplicates, of cross referencing, and of verifying references all had to be done by the user before the interpretation and evaluation of the data could begin.

A considerable number of the entries were from the trade journal literature and were essentially descriptions of commercial products. Many open literature articles that had already been uncovered were not included (principally those appearing in the journals which are not directly related to the fields of metallurgy and ceramics, *e.g.*, the *Journal of Applied Physics*,[14] and the chemistry journals). Very few articles appeared from the foreign literature, particularly the English and the German, where considerable work has been done in the refractory materials area. On the other hand, the search did tend to show considerable literature from the Russians and the Japanese. Perhaps this reflects the extreme interest during the past ten years in anything that the Russians are doing. There are approximately 300 scientific magazines and journals in which metallurgy and ceramics information is reported and is consistent with the ASM's stated list of their coverage. However, only approximately 20–25% of these were represented in this machine search.

With reference to the abstracts themselves, it is felt there is considerable room for improvement. Quite often

it was necessary to trace the references back to a standard abstract journal or even to the original reference; most times the abstract journal citation was inadequately given. An abstract from *Chemical Abstracts* or *Nuclear Science Abstracts* was invariably more informative and always substituted where possible. We realize that ASM is not designed to provide specific data, to interpret, or to evaluate, but even the "indicative" abstract failed to "indicate" whether the reference contained new or specific information, or whether it was of general pseudo-technical nature written for the lay public.

As mentioned previously, it was felt that much of the refractory materials research effort was described only in the "report literature." The ASM search did substantiate this preconceived conclusion. A considerable number of the abstracts were for reports generated under research contracts sponsored by the Air Force, Navy, and Army. The reports generated under the Atomic Energy Commission programs were not well covered. These findings confirmed the fact that the meat of the work in the refractory materials research area is appearing only in the report literature. The bulk of this information has not yet appeared in the open literature and it is doubtful that it ever will.

At the conclusion of a contract, experimental researchers are often quickly transferred to some other project, and it becomes increasingly difficult to prepare papers for the open literature which would well document their research work. Thus, most of this work is left buried in the report literature and can go relatively unnoticed.

To add to this problem, much of the refractory material research is being conducted under systems development programs. The work is reported in the over-all progress reports on the development of the system and thus, becomes difficult to find. Programs administered by ASD, BSD, and SSD of AFSC such as the Dynasoar, the classified Advanced Reentry Program, and the Polaris administered by the Special Projects Agency of the Naval Bureau of Weapons are examples, and as such this information is available only to the requestor either through the contractor or the technical information center of the specific administering agency. A report published by the Lockheed Aircraft Corporation required nine months to obtain through ASTIA.[9]

How could this literature research program be simplified? First, having a specialized information agency (similar to DMIC) functioning in this area would not only have provided the background material over the immediate past, but will also provide the experimental researcher with the periodic reviews that are required.

Secondly, it would have been highly desirable to have a trained literature specialist function as an integral part of the technical project. By being familiar with the literature desires of the research group, the literature specialist can supply the pertinent material on a day-to-day basis.

Thirdly, a more competent job of reporting on the part of the researcher would have clarified much of the ambiguity in the relating the thermophysical and mechanical properties of these materials with the characterization parameters. Much of this work being reported in the literature is not amply described with reference to such things as chemical composition, stoichiometry, grain size, and density. Because of this it becomes extremely difficult to relate individual pieces of research with respect to their determination of mechanical and physical properties.

And, lastly, more comprehensive data compilations would have helped immeasurably. It is urged that more frequent and thorough compendia be generated along the lines which have been described previously.

REFERENCES

(1) R. I. Jaffee and D. J. Maykuth, "Refractory Materials," Defense Metals and Information Center, February 26, 1960, DMIC Memo 44.

(2) A. Goldsmith, T. E. Waterman, and H. J. Hirschhorn, "Handbook of Thermophysical Properties of Solid Materials," 5 vols., The Macmillian Co., New York, N. Y., 1961.

(3) C. Agte and H. Alterthum, *Z. Tech. Physik.*, 11, 182 (1930).

(4) Stanford Research Institute, Proceedings of International Symposium on High Temperature Technology, Asilomar, California, 1959, McGraw-Hill Book Co., Inc., New York, N. Y., 1960.

(5) I. E. Campbell, "High Temperature Technology," John Wiley and Sons, Inc., New York, N. Y., 1956.

(6) P. Schwarzkopf and R. Kieffer, "Refractory Hard Metals: Borides, Carbides, Nitrides, and Silicides," The Macmillian Book Co., New York, N. Y., 1953.

(7) C. F. Powell, I. E. Campbell, and B. W. Gonser, "Vapor-Plating: The Formation of Coatings by Vapor-Deposition Techniques," John Wiley and Sons, Inc., New York, N. Y., 1955.

(8) W. D. Smiley, L. E. Sobon, and F. M. Hruz, "Mechanical Property Survey of Refractory Nonmetallic Crystalline Materials and Intermetallic Compounds," Jan., 1960, WADC TR-59-488, AD 234-775.

(9) W. G. Bradshaw and C. O. Matthews, "Properties of Refractory Materials: Collected Data and References," Lockheed Aircraft Corporation, Missile and Space Division, June 24, 1958, LMSD-2466, AD 205-452.

(10) H. H. Hausner and H. C. Friedemann, "High Temperature Compounds, A Data Book," General Astrometals Corporation, New York, N. Y., 1962.

(11) J. H. Westbrook, Ed., "Symposium on the Mechanical Properties of Intermetallic Compounds, 1959" John Wiley and Sons, Inc., New York, N. Y., 1960.

(12) C. Tipton, "The Reactor Handbook," Vol. 1-"Materials," 2nd Ed., Interscience Publishers, Inc., New York, N. Y., 1960.

(13) F. J. Koubek, H. Perry, and I. Silver, "Polaris Materials Program," Naval Ordnance Laboratory, White Oak, Maryland, Feb., 1958, NAVORD-6056, AD 158-518.

(14) W. Williams and R. Schaal, *J. Appl. Phys.*, **33**, 955 (1962).