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RAPID SOLIDIFICATION TECHNOLOGY

Report of the First Workshop

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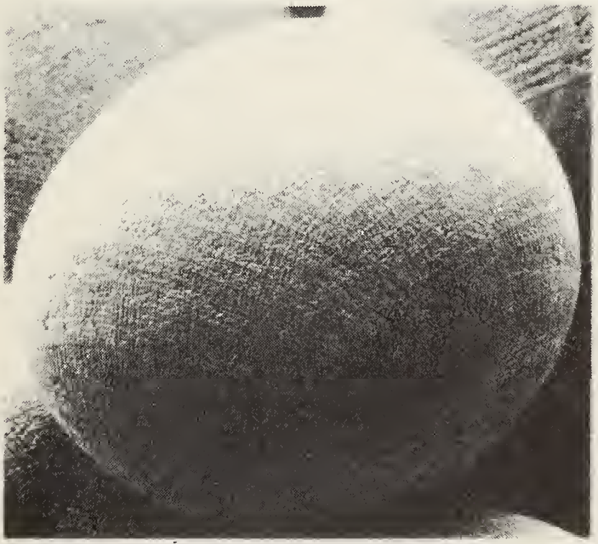

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Sponsored by
Committee on Materials (COMAT)
Ad Hoc Working Group on RST

Hosted By
National Measurement Laboratory
National Bureau of Standards

RAPID SOLIDIFICATION TECHNOLOGY

Report of the First Workshop

NATIONAL BUREAU OF STANDARDS
GAITHERSBURG, MARYLAND

July 1–2, 1981

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INTRODUCTION

The first Briefing/Workshop on Rapid Solidification Technology (RST) was convened on July 1-2, 1981 at the National Bureau of Standards in Gaithersburg, Maryland. It was sponsored by the Office of Science and Technology Policy Committee on Materials (COMAT)/Rapid Solidification Technology Ad Hoc Working Group.* The aim of this Briefing/Workshop was to first provide the private sector with the government-wide implementation strategy for RST in the next five years; and second, to seek industry/university input and involvement in order to effect a wider range of applications of this technology-based "breakthrough." This report is the proceedings of the deliberations from the Workshop portion of the meeting. The material was obtained from detailed notes and summaries given to us by the Recorders and Moderators of the three different Workshop Task Groups. A preliminary draft of proceedings was forwarded to the Moderators, the Briefing/Workshop Coordinating Committee* and the COMAT Ad Hoc Working Group for their comments and suggestions. The inputs received are incorporated in the final version of the report presented here.

The major attention of RST has been directed toward the development of processes which would permit achievement of fast cooling rates from the pre-alloyed liquid state. Such processes have typically involved: (a) solidification of small droplets, followed by their subsequent consolidation via powder-metallurgy techniques into bulk-pieces and net shapes, or (b) the melt spinning of continuous or discontinuous lengths of filaments and thin ribbons, or (c) the *in situ* melting, sometimes coupled with alloying and compositing, of metallic surface layers.

*Lists of the members of the Ad Hoc Working Group and the Briefing/Workshop Coordinating Committee are given on pages iv and v, respectively.

There is ample evidence that rapid solidification of pre-alloyed liquids leads to improved homogeneity, structural refinement, control of grain size and precipitate distributions in the resulting solid. For certain alloy compositions, the solid forming is amorphous and possesses exceptional magnetic properties. A further important aspect of this new technology is the development of new alloys with reduced segregation which will lead to cost-beneficial properties in final shapes or coatings of technological importance.

The advent of RST has catalyzed new ideas across the wide spectrum of alloy structures, properties, and performance. A number of useful new alloys and products have already emerged from this rapidly evolving field. At the same time, striking advances have been made in our understanding of the phenomena associated with rapid solidification, which promises to further expand the areas of applications.

This Briefing/Workshop stemmed from our recognition that in order to achieve a wide-scale exploitation of this new technology university/industry input, involvement and support should go along with the implementation of the government-wide program. A number of U.S. firms are already conducting in-house research and development programs directed at their product lines. Some industrial laboratories are investing in new methods for producing rapidly solidified alloys. It is much too early to predict which methods will best produce superior products in a cost-effective way, but it is safe to assume that a variety of techniques will emerge which are tailored to specific manufacturing processes.

During the first day of the meeting, coordinated briefings were given of the government-wide program and implementation strategy. The specific lectures for the

Briefing were prepared jointly by the Coordinating Committee of the Briefing/Workshop. The program for both the Briefing and the Workshop is given in the Appendix to this report.

A Workshop/Task Group format, organized by industry sectors (i.e., ferrous and specialty materials, light alloys, and superalloys industries) was followed on the late afternoon of the first day and throughout the second day to permit a wide range of inputs from the attendees. The majority of the two hundred and seventy five Workshop participants were from industry. The actual percentages were: 68 percent from industry, 11 percent from academia and 21 percent from government. These percentages also reflect a fair representation of participation in the three Workshop Task Groups. The number of participants in the Task Groups were: 102 in Ferrous and Specialty Materials, 75 in Light Alloys, and 98 in Superalloys.

Two to three Moderators (from outside the government) were assigned to each Workshop Task Group. The Moderators first discussed pre-selected questions to be addressed by the Workshop. Input was sought from the participants on other questions of importance for the Workshop agenda. For example, two of the pre-selected questions were modified in the Superalloy Workshop and four new questions were added at the suggestion of the participants. An assigned speaker initiated the discussion on each question with a five- to ten-minute presentation, thus opening avenues for further deliberations. At the end of the apportioned time for the question, the Moderators summarized the conclusions and recommendations emanating from the discussion and moved on to a new subject. At the end of the second day the Moderators of each Workshop Task Group reported the findings to all the attendees in a joint final session.

FERROUS AND SPECIALTY MATERIALS

The participants in this Workshop proved to have a wide range of interests, reflecting the differently oriented constituencies in crystalline vs amorphous materials, in structural vs magnetic materials, and in the disparate nature of the ferrous metallurgy field as it is beginning to learn about RST. The available time for this Workshop was divided between crystalline ferrous materials and amorphous alloys.

Moderators: M. Cohen, M.I.T.

L. A. Davis, Allied Corporation

E. J. Dulis, Crucible Research Center

Recorders: D. E. Polk, ONR

S. Isserow, AMMRC

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A. Lawley, Drexel University

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L. A. Davis, Allied Corporation

L. A. Johnson, General Electric Corporation

P. R. Strutt, University of Connecticut

J. Dickson, Allied Corporation

1. What are the main principles and guidelines which have now emerged regarding the rapid solidification of crystalline ferrous alloys?

- Refined segregate structures and compositionally more uniform structures are produced.

- Second-phase dispersoids are refined, and sometimes new phases are formed.

- The range of useful alloy compositions is expanded, for example, through extended solid solubility of solute elements.

- Grain size is reduced, but this also depends on subsequent processing. Resistance to grain growth at high austenitizing temperatures has been noted through pinning of grain boundaries by finely dispersed second-phase particles. Thus, second-phase particles can play an important role in achieving a combination of strength and toughness.

- Mechanical and chemical properties are improved in specific alloy systems.

- Advantages and disadvantages are noted when the powder metallurgy route is followed, for example, in applications based on mechanical properties.

Other comments of relevance included the following:

- Alloy design can be aided by considering the thermodynamics of second-phases, so that extremely stable second-phase particles can be incorporated. The role of fine second-phase particles on the kinetics of grain coarsening can be related to Ostwald ripening of the particles. Thus, thermodynamic data for solubility products and diffusivities of the operative elements are needed for estimating the stability of second-phase particles.

- Some of the principles outlined can be equally applied to other alloy systems, and the potential benefit of stable distributions of fine precipitates need not be limited to pinning of grain boundaries. For example, large volume fractions of fine precipitates can be effective for dispersion strengthening.

- More work is needed to establish the relationships between alloy composition and process variables on the formation and stability of second-phase particles.

- Additional fundamental and engineering data are needed in several areas; these include welding, secondary recrystallization, ability to exploit the high austenitizing temperatures, and critical element substitutibility.

- A present bottleneck to fundamental and developmental studies is the availability of adequate amounts of high-quality rapidly solidified materials. Facilities for research materials, if established, should use several particulate production methods.

2. What are the important needs for further research on the various steps from rapid-solidification and particulate-consolidation methods to final properties in order to move toward the engineering application of ferrous RST?

- Attainment of microcrystalline, segregation-free solids by rapid solidification is influenced by both the heat extraction rate and the degree of undercooling. The role of heterogeneities, endogenous (melt composition and cleanliness) or exogenous (melt reactions with crucible or quench medium), on nucleation rate and achievable undercooling should be investigated more systematically.

- Attention should be given to single-variable rapid solidification experiments to establish the effects of different atomization processes and powder sizes on microstructure and properties.

- Work is required to delineate the influence and relative importance of powder production method, consolidation method, and process variables, as well as the effect of post consolidation heat treatments on the structure and properties of the final product.

- Work is needed on new consolidation approaches, in particular high-rate, low-temperature and direct densification techniques.

- Melt spinning of crystalline ferrous alloys, the product of which is subsequently broken into fine particles, should be studied. Advantages could include more uniform cooling conditions (for a given melt composition and cleanliness) and easier quality control. Possible contamination from the chill material could be a disadvantage.

- The effect of particulate size and geometry (including melt-spun particulates) on packing density and densification mechanisms should be investigated.

3. What are the prospects for the engineering application of RST to typical ferrous products, such as tool steels, bearing steels, corrosion- and oxidation-resisting steels, etc.? What are the present roadblocks?

- The principal current application of RST in crystalline ferrous alloys is in high-speed tool steels, which commands less than 5% of the market. Conventional alloys have been improved through RST by reducing micro-segregation and carbide size.

- New ferrous alloys, unique to RST, are being developed which have the advantage of critical materials substitutibility or superior performance. Examples include the development of cobalt-free high-speed steel replacements for M42 and T15, high chromium- and vanadium-containing alloys with improved corrosion and wear resistance, and high vanadium tool steels with unusually high wear resistance.

- Cost has an important bearing on broader acceptance of various low alloy ferrous RST products. The prices of current RS and conventionally produced high-speed tool steels are about the same.

- Cost and quality-control considerations pose roadblocks for other engineering applications. The value-added concept - including cost/benefits of the entire component based on its life cycle and not just the initial cost of material - should improve competitive pricing of RST materials. Strict quality-control procedures are needed.

- Production of large net shapes, hollow shapes, and composites have engineering advantages for RST that could be exploited.

4. What are the prospects for scaling-up rapid solidification techniques for cost-effective production?

- Prospects for scale-up appear very good. Production facilities are presently available which are capable of producing several hundred tons/month of intermediate cooling-rate atomized particulates.

- A principal roadblock here involves convincing companies that there is a demand for RST products and that the demand will be lasting. Technical and economic information must be generated which will convince producer and user management that investment in RST is sound business.

- NMAB is currently conducting a study (1) to survey existing facilities for rapid solidification and subsequent consolidation, and (2) to assess the potential of new emerging processes.

- The experience gained by industry in the melt spinning of amorphous materials suggests that this method of rapid solidification should also be investigated for crystalline alloys. Thorough comparisons should be made with the atomizing approach from the standpoints of both the quality of the rapidly solidified materials produced and the efficiency of the subsequent consolidation steps. These considerations are also relevant to future decisions concerning scale-up and cost-effectiveness.

- Based on the current commercialization of RST for tool steels, the eventual technology-transfer to industry for many other ferrous applications looks favorable particularly for specialty alloys.

5. Are the conclusions and recommendations put forth in the NMAB report adequate as guidelines for establishing national policy regarding development of rapidly solidified amorphous alloys technology?

- The study did not aim to establish such guidelines. It was too broad in scope and most of its conclusions/recommendations dealt with crystalline materials. Furthermore, the study was conducted in 1979 and is therefore slightly out-of-date.

- Up to now, most of the funding for R and D on amorphous alloys in the United States has come from industry rather than from the government. In Japan, the trend appears to be the opposite. For example, Nippon Steel was recently awarded a $9 million contract to develop amorphous-alloy sheet for transformers.

- A plea was made for a strong governmental program in the design and manufacture of new transformers that would take full advantage of the lower core losses of amorphous alloys. The prevailing weak transformer market in the United States coupled with strong cooperation between government and industry in Japan could lead to a world market dominated by Japanese manufacturers.

6. What are the economic and other driving forces and barriers for application of amorphous alloys?

- In the past decade, significant progress has been made in process development, alloy design and characterization of amorphous alloys. The broad spectrum of activity in this field is evidenced by the approximately 400 papers presented at the 1981 Fourth International Conference on Rapidly Quenched Metals in Japan.*

- Largest current potential use of amorphous alloys is in electromagnetic applications. For example, alloys have been formulated which exhibit $\sim$1/4 of the core losses of Fe-3%Si, which is the standard magnetic core material in power-distribution transformers.

- Potential energy savings provide the economic driving force for the use of amorphous alloys to replace Fe-Si. One estimate predicts a $30 billion saving over the next 15 years - this includes savings which would accrue due to reduced need for new generating capacity, amounting to seven 1000-megawatt stations.

- In addition to soft magnetic properties and low core loss, metallic glasses exhibit other notable magnetic properties, such as high magnetostriction, low acoustic loss, high permeability, high corrosion resistance, and temperature-dependent permeability. Thus, they have the potential for myriad of applications in devices, including magnetostrictive transducers, load cells, electric motors, magnetic amplifiers and phase shifters, magnetic separators,

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*This information became available subsequent to this Workshop.

magnetic shielding, thermosensor, magnetic recording heads (audio, video, digital), and others. Efforts in the latter areas are primarily conducted by device manufacturers in Japan.

- Barriers to application of amorphous alloys are primarily economic and institutional rather than technical. They include: cost of materials (boron dominates raw material cost, 85%), cost to develop a new design and the corresponding manufacturing technology, availability of lower-cost competing technologies, and lack of multiple suppliers. On the other hand, the driving force in Japan is stronger due to the higher cost of energy - several times higher than in the U.S.

- Some cost/production questions are being answered at the ∿5,000 ton/year facility at Allied Corporation.*

- Other potential applications of amorphous alloys are envisioned due to their special engineering properties. These include: brazing materials (already commercialized in the U.S.), razor blades, radiation shielding, corrosion-resistant pipes or sheets, etc.

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*A major joint Allied Corporation - Japan amorphous alloys venture was announced subsequent to the July 1-2, 1981 Workshop. The joint venture with four Japanese companies of the Mitsui Group, led by Mitsui Petrochemical (and including Toshiba), resulted in the formation of a new company NAMCO (50 percent shared by Allied) and an exclusive Asia license to same for the technology and patents.

7. What are the prospects for surface treatments by rapid solidification methods for both crystalline ferrous and metallic glasses? What are the present roadblocks?

- There is good evidence that rapid solidification by directed high-energy sources confers significant resistance to oxidation, corrosion and wear through surface melting, alloying and compositing.

- Studies are needed to better define specific processing/structure relationships and to determine mechanisms for the enhancement of surface properties.

- Directed energy beam characterization and control issues coupled with a lack of predictive models relating processing/structure/properties pose strong barriers to applications at the present time.

- There is the prospect that surface melting can be automated and coupled to other surface treatments such as plasma spraying. Cost saving could thus be realized by imparting superior surface performance to inexpensive bulk materials.

- More service testing of surface-modified components is needed.

8. What are the prospects and roadblocks for the development of bulk rapidly solidified components using the glassy state as a "pathway" to microcrystalline structures?

- Amorphous alloy formation is already being investigated as an alternative "pathway" to the formation of crystalline structures. Bulk microcrystalline structures are being synthesized through crystallization and consolidation of new families of amorphous alloys specifically designed for this purpose.

- Devitrification of amorphous alloys produces a fine mixture of metallic phases and borides. Investigations are underway to test the consolidated materials in a variety of tool, die and wear-resistant applications.

- Thus far, this route appears to generate a finer grain size than that obtained by rapid solidification directly to the crystalline state. On the other hand, compositional ranges are limited to those that can avoid crystallization under the available cooling rates from the liquid state, as well as to those that do not weld to or damage the chilling substrate.

- Comparison of properties should be performed on RS alloys of the same composition formed by alternative methods. For example, one would be devitrification of an amorphous alloy while the other would be direct microcrystalline solidification.

- The mechanism of wetting/adherence, important in melt spinning, is not sufficiently understood and needs further study if the process is to be applied to a wider range of alloys, including those that solidify in the crystalline mode.

9. What is necessary in order for the government-wide programs on rapid solidification (a) to stimulate increased research efforts in industry and in academia, and (b) to encourage the commercialization of RST? What are the barriers to overcome?

- The government does not yet have a coordinated and viable program in the RST of ferrous alloys, as is already the case for aluminum alloys nor is it as well supported as is work in superalloys. The overall potential for steels is at least as great as for the other two classes of materials. Indeed, the latter two programs provide prototypes for what needs to be done in the way of coordination, goal setting, and funding for the RST of ferrous alloys.

- The steel industry seems to be quite curious about RST, but it is not yet particularly excited about it. While there was considerable "diffusion" of new information to the ferrous segment of the audience, this was apparently not sufficient to stimulate the start-up of research programs "back home". The general attitude remained one of "we will still wait and see".

- The problem of easier access to rapidly solidified as well as to consolidated ferrous materials was expressed over and over again, but it was clear that the intended applications will be extremely varied and multiple facilities will be needed to cope with the supply problem.

- There is a need for concrete evidence of improved properties via RST all the way to "prototype" demonstration. This will help stimulate a market pull for RST products.

- The steel industry is more "diffuse" in comparison to light alloys and superalloys. The tool steel and amorphous alloy technology commitments were made by companies with little or no governmental support. Improved communication between users and suppliers of ferrous materials will aid in identifying specific products which could gain from RS manufacturing methods.

- There is now ample evidence that Japan is making a strong commitment to commercialization of amorphous alloy products - see questions 5 and 6. The prevailing trend is likely to lead to another new technological market dominated by Japanese products.

LIGHT ALLOYS

Moderators: R. Spear, ALCOA

R. V. Carter, Boeing Commercial Airplane Co.

Recorders: D. P. Voss, AFWAL

M. Greenfield, NASA

J. Waldman, U.S. Army Armament R and D Command

Speakers: R. Athey, Pratt and Whitney Aircraft

R. V. Carter, Boeing Commercial Airplane Co.

W. S. Cebulak, ALCOA

N. J. Grant, M.I.T.

G. E. Spangler, Reynolds Metals Co.

1. (a) Are the conclusions and recommendations put forth in the NMAB report adequate as guidelines for establishing national policy regarding rapidly solidified (RS) aluminum alloy development?

- Yes. However, some of the conclusions paint too optimistic a picture of aluminum alloy RST without an adequate data-base.

- No RS aluminum alloy has yet attained commercial production status.

- Near term opportunities for commercial applications are limited to the aerospace industry.

- There has been no in-service experience for RS aluminum alloys. Such experience is needed on a variety of components, especially where superior performance and/or total life-cycle cost savings are expected.

- Insufficient number of new alloys have been developed and studied to date.

1. (b) Is the current national program addressing the needs stated in the recent NMAB study?

- The government-wide RS aluminum alloy program has two major thrusts: (1) near-term (by 1985) attainment of production status for first generation alloys, with moderate property improvements, to develop operating and in-service use experience, and (2) longer-range (by 1990) development of advanced alloys, with significantly large property improvements, coupled to generic studies to advance the underlying science-base.

- More work is required to relate the microstructure/property observations in RS aluminum alloys to thermodynamic, kinetic and heat flow concepts.

- Cost versus performance analysis is required for specific commercial aircraft components.

- Programs are needed aimed at in-service experience and round robin tests on RS aluminum alloy products by various aerospace companies.

- Impetus is needed for producers to make different RS aluminum alloy products available for user evaluation.

2. What are the envisioned applications of rapidly solidified aluminum alloys?

   (a) In the aerospace industries?

   (b) In other than aerospace industries?

- In general, the extent of applications for RS aluminum alloys will depend on the total life-cycle cost, property improvements achieved, demonstrated in-service performance and availability of production quantities of quality material.

- Near-term opportunities for commercial applications are limited to the aerospace industry. Significant other commercial applications have yet to be identified.

- Cost-competitiveness with respect to improved ingot metallurgy aluminum alloys, titanium alloys and composites is an important consideration in aerospace applications.

- The driving forces for aerospace application are improvements in modulus-and/or strength-to-weight ratio, resistance to stress corrosion cracking, general corrosion, fatigue and fracture toughness.

- RS aluminum alloy suppliers need input from the marketplace (the user industries) on their property goals, volume and the product form needs.

- There has been little in-service experience for RS aluminum alloys. Such experience is needed, even if it is on non-critical components, in order to instill confidence in the user community.

- In the near-term, substitution for components in existing aerospace systems should be emphasized. It is not likely that the design of new systems will include untested materials which have not achieved production status.

- The value of weight saved in a component may depend on the location and application of the component in an aircraft.

- Non-aerospace applications of RS aluminum alloys are almost entirely in the transportation industry (e.g., connecting rods in internal combustion engines). Cost-effectiveness in non-military applications will be the critical factor.

3. What are the critical issues in early commercialization of rapidly solidified aluminum alloy products:

(a) with respect to production of large quantities of particulate of uniform quality?

- In the near-term, there is no forseeable problem in the production of large quantities of relatively uniform quality RS X7090 and X7091 aluminum alloys.

- Process R and D is needed to address observed microstructural variations, especially variations in second phase particle size, in other RS aluminum alloys.

- The production of lithium-containing RS aluminum alloy particulate will present special problems due to the reactivity of this element.

(b) in the cost effective manufacture of billet, sheet and plate?

- The production cost of RS aluminum alloy products will have a great influence on their ultimate utilization.

- Scale-up of RS aluminum alloy billet, plate and sheet production is difficult and costly - it requires new facilities and the particulate is reactive. This is a critical aspect of the near-term problem in commercialization.

- Total life-cycle cost savings in existing systems need to be identified based on improved performance - durability and/or reduced density. This will stimulate early demonstration/application of RS aluminum alloys.

- Work is needed on new consolidation approaches for aluminum RST. For example, significant cost savings will be realized by eliminating encapsulation during billet processing. Manufacture of preform billets for subsequent net-shape forging may be another approach.

- Investment in new facilities for billet manufacture (e.g., cold and vacuum hot pressing) needs to be justified on the basis of an available, cost-effective, market for the RS aluminum alloy products.

- Vacuum pre-heating, with its attendant cost penalty, has been shown to have a major positive effect on fracture toughness (especially short transverse) of RS X7090 and X7091 alloys.

- Appropriate billet sizes and geometrics have to be identified for extrusion, forging, plate, sheet and other products.

4. What are the key technical considerations in the consolidation processes and thermomechanical treatments, with respect to the control of metastability and 100% densification?

- In the near-term, adequate thermomechanical treatments (TMT's) are available for RS X7090 and X7091 aluminum alloys.

- Conventional TMT practice may not be applicable to the perservation of metastable structures obtained in other RS aluminum alloys. In the long term, development of special TMT's may be required to fully utilize RST alloys.

- The effect of heat treatment on the microstructure of aluminum alloy particulates should be studied with and without the influence of the consolidation operations.

- Direct HIP to final product is not currently a viable approach for RS aluminum alloys due to particulate surface contamination.

- Studies are needed on the effect of alloy composition and solidification variables (undercooling, liquid/solid interface velocity, etc.) on the formation and stability of supersaturated matrices and second phase particles.

- Detailed quantitative microstructural analysis of RS aluminum alloys and failure modes are needed. For example, coarsening of fine second phase particles, their role on pinning of grain boundaries, and crack initiation and propagation in fatigue needs to be studied.

- Guidelines need to be developed for the design of "ideal" microstructures for RS aluminum alloys to achieve desired properties.

- Many RS aluminum alloys represent incremental changes of conventional wrought or cast alloys. More attention should be given to radical departures in alloy design to produce the "ideal" microstructures noted above.

- Studies are needed on the hot working characteristics of RS aluminum alloys.

5. (a) Is there a need for improved sources of high quality, research quantity, rapidly solidified particulate? Should this be supplied by government supported central facilities?

- Sources for high quality, research quantity, RS aluminum alloy particulate are needed.

- There is also a need in the community for a variety of RS aluminum alloy billets and mill products for characterization and performance analysis.

- Intermediate size extrusions of two RS aluminum alloys are now available. More sources are needed including those using the direct powder-to-mill product route.

- Users should not be dependent on a single government or other source for RS aluminum alloys. Industrial and other facilities should be encouraged to participate in the supply of particulate and consolidated materials.

5. (b) Will the government-wide program stimulate strong university/industry involvement, as well as industry investment? If not, why not? What other actions are deemed desirable to achieve this objective?

- Yes. The government-wide program does stimulate participation and investment.

- In the near-term, more government support is needed for component demonstration programs.

- In the long-term, sponsorship of more fundamental programs is encouraged in the areas of phase stability and microstructure control during solidification and TMT.

SUPERALLOYS

Moderators: A. L. Bement, Jr., TRW, Inc.

H. J. Klein, Cabot Corporation

Recorders: A. M. Adair, AFWAL

L. A. Jacobson, DARPA

J. R. Manning, NBS

Speakers: E. M. Breinan, United Technologies Research Ctr.

W. H. Couts, Jr., Wyman-Gordon Co.

A. Lawley, Drexel University

D. Maxwell, TRW, Inc.

J. B. Moore, Pratt and Whitney Aircraft

S. H. Reichman, Special Metals Corporation

R. G. Rowe, General Electric Company

J. C. Williams, Carnegie Mellon University

R. F. Wojcieszak, General Electric Company

1. (a) Are the conclusions and recommendations put forth in the NMAB report adequate as guidelines for establishing national policy regarding rapidly solidified superalloy development?

- The emphasis of the NMAB study was on superalloy turbine disk applications. Therefore, the report is not broad enough in scope to be used as a guideline for other RS superalloy applications.

- Some of the conclusions and recommendations of the NMAB report; for example, those dealing with the fundamental aspects of RST, the need for low cycle fatigue (LCF) data, and the problems associated with ceramic inclusions and quality assurance (QA), were discussed during this Workshop. Consensus reached during the deliberations are noted in the various segments of this summary.

- Recommendations should be prioritized in future NMAB reports on RST.

1. (b) Is the current national program addressing the needs stated in the recent NMAB study?

- This question was not directly addressed due to lack of relevant data. However, there was discussion about what the government should do.

- For disk applications, data from standardized test procedures for LCF are needed. Furthermore, factors that affect crack initation and propagation should be identified in order to assess the influence of RS on LCF.

- Government support is needed to develop fatigue resistant alloys and melting methods for powder production that avoid melt contact with ceramics.

- Superalloy powder materials for disk applications offer higher strength than can be obtained from cast and wrought products; however, a trade-off must often be made between higher strength and defect tolerance. Powder cleanliness is a key issue that should be addressed in conjunction with QA.

- Proposed government programs put too much emphasis on powder production methods and not nearly enough effort on consolidation techniques. The latter is important and should be fully addressed.

2. Is there a need for more work on structure-property relationships and the effect of heat treatment on stability in rapidly soldified superalloys?

- Yes. Furthermore, it is important that an exploratory attitude be maintained regarding opportunities for development of new RS superalloy microstructures.

- RST opportunities for microstructure development are much broader than conventional practice. Work on computer-based phase stability data compilation coupled to predictive models could provide a better description of phase relations (both equilibrium and metastable) for design of new alloys and microstructures.

- There is a need to systematically determine how consolidation and subsequent thermomechanical processing variables affect the structure-property relationships in specific component parts.

- There is a need to define and conduct specific research programs in the structure-property area. Guidance and participation should be sought from a spectrum of qualified scientific experts in the field.

- Fundamental work is required on the high temperature stability of RS superalloys. Instability has been observed in the form of discontinuous γ' coarsening at the grain boundaries of a number of consolidated RS nickel base alloys. The mechanisms responsible for this phenomenon are not yet understood.

- Research is needed to provide thermodynamic data for solubility products important in estimating the stability of primary and secondary phases in RS superalloys.

- Guidelines are needed based on kinetic and thermodynamic solidification theory for alloy design, prediction of phase sequences and control of processes and microstructures.

3. Is the lack of suitable techniques for detection and separation of non-metallic and other foreign inclusions from metallic powder a major roadblock to useful application of superalloy powders?

What can be done to correct this problem?

- It is a serious matter and of prime concern, but not a major roadblock. Many components made from complex superalloy powders have been flying successfully. Specific information should be documented on the highest number of engine cycles experienced.

- Non-metallic and other foreign inclusions have been shown to reduce the fatigue life of superalloy P/M material depending on the size, composition and the volume fraction of the inclusions.

- Inclusions may originate from both master melt contamination and the powder production process. Improved powder processing techniques and better methods for the detection and separation of inclusions are needed to extend the range of applications for RS superalloy parts and/or to improve their performance.

- Improved powder processing techniques can include cleaner feedstock, better melting practice, no melt contact with ceramics and all inert powder handling.

- It is important to detect and separate out inclusions before consolidation. For example, better refined elutriation methods are needed.

- Defect appearance in failed test specimens is related to the type of test, specimen size, strain range, etc. In order to keep RS superalloy powder usage an accepted technology, we must continually explore the products for evidence of defects, and characterize them well.

- The Workshop recommends that ASTM initiate work on cleanliness standards for RS superalloy powders.

- Consideration should be given to improve defect tolerance of RS superalloy products through changes in alloy chemistry, production of fine powders and thermomechanical treatments.

4. What policies, programs, or financial support are needed to assist producers, users, and designers in developing confidence in RS superalloy technology?

- In the long run capital expenditure by producers depends on the civilian market. Furthermore, large investments are necessary to requalify critical components. Therefore, it is recommended that the government sponsor RST programs on some non-critical parts so that hands-on experience can be gained by the producer and confidence can be established in the user industries.

- Data-base is needed by designers on the effect of inclusions on properties of RS superalloys. It is recommended that government programs be established to measure the effect of controlled addition of inclusions on properties using standarized test methods.

- The need for improved processing techniques, noted under question 3 above, was reiterated. For example, the potential use of EB or laser melting to eliminate ceramic crucibles should be investigated.

- Designer confidence in RST must be gained by successful component testing and uniform acceptance tests for QA.

- Other options for producing "RS properties" in superalloys should be examined in terms of process economics.

5. What market sectors will benefit most over the next ten years from rapid solidification technology?

   Where are the major opportunities in superalloys?

- Markets for RS superalloys can be broadly identified in the gas turbine engine for aircraft, ground transport and power generation - where fuel efficiency is of prime concern.

- Disk RST is anticipated to show rapid growth in both the military and the commercial sectors.

- No RS superalloy has yet been designed for disk - specific applications. Alloy development programs should emphasize low cost, strategic element content, improvements in fracture toughness and LCF.

- No application for RS superalloy airfoils is seen in a commerical aircraft engine over the next ten years. On the other hand, military applications are envisioned during the same period.

- Development of new RS iron-base alloys offers potential cost savings and freedom from import dependence if it can replace the 3.5 million pounds of cobalt-base superalloy cast in 1980 for the industrial machine hardware sector.

- Nickel availability and cost has been a deterrent to serious consideration of superalloys for the automotive turbine. The development of a new RS iron-base alloy could have an important impact on this technology.

- Advanced forming concepts for low cost components for use in vehicular engines will greatly affect market applications. For example, combined forging/extrusion processes are needed to produce integrally bladed turbine wheels.

- Applications for RS superalloys have been identified in energy conversion systems and deep oil well tooling.

- Nickel base RS alloys are being developed for tool and die applications.

- The catalytic effectiveness of Raney nickel can be improved significantly by rapid solidification before leaching out the contained aluminum. This has been shown in the synthesis of methanol from natural gas and in other reactions of commercial interest.

6. Can surface processing lead to important commercial applications involving superalloys?

- Yes. The economic analysis of surface processing identifies the limiting problem to be energy deposition rate. This limitation opens a window of opportunity for high power density directed energy processing.

- The field of RST surface processing needs stronger support to establish possible microstructure/property improvements. Cost-benefit analysis is also needed.

- RST surface processing of superalloys could make important contributions to rework and repair of components.

- Cracking of high γ' nickel-base superalloys is a severe problem in directed high energy processing. Non-destructive techniques could be developed for crack detection and on-line control of process parameters.

- RST surface processing offers the potential for upgrading acceptability of surface coating technology because of improvements in microstructural uniformity. More automation will be required to optimize process economics.

7. (a) Is there a need for improved sources of high quality, research quantity, rapidly solidified particulate?

Should this be supplied by government supported central facilities?

- Yes. Many different needs are evident. A strong endorsement is given to help establish this capability at NBS as part of their overall responsibility for Standard Reference Materials.

- It is also recommended that selected NSF funded Materials Research Centers participate in the production of research quantity RS particulates.

- A survey should be conducted of university and other facilities to determine capabilities for RS particulate production and consolidation.*

7. (b) Will the government-wide program stimulate strong university/industry involvement as well as industry investment? If not, why not? What other actions are deemed desirable to achieve this objective?

- University/industry co-participation has been stimulated by the government program.

- Contractor commitment and investment has been one of the quid-pro-quo's in contractor selection. This is endorsed as future policy.

- Qualified not-for-profit institutes should participate in the overall RST program.

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*Such a survey is presently underway as part of a new NMAB study on RS processing.

- It is recommended that COMAT bring the Metal Powder Industries Federation (MPIF) into their planning activities.

8. How do powder production and subsequent processing techniques interact to yield a product that is defined as "RS"?

- A good review of these interactions is given in the paper by M. Cohen, B. H. Kear, and R. Mehrabian "Rapid Solidification Processing: An Outlook", Rapid Solidification Processing: Principles and Technologies II, R. Mehrabian, B. H. Kear, M. Cohen, eds., Claitor's Publishing Division, Baton Rouge, LA (1980).

- There is a need to balance emphasis on heat extraction rate and other factors, such as nucleation rate and undercooling governing the attainment of unique microstructures.

- In general, definition of rapid solidification processes in terms of just high cooling rates has led to confusion. A measure of rapid solidification processing could be the cooling rate of an alloy at its liquidus temperature since this rate influences the "incubation period" available for nucleation. On the other hand, fineness of microstructure is usually correlated to average cooling rate during solidification or time available for coarsening. Finally, many structural manifestations of rapid solidification are best correlated to the solid-liquid interface velocity.

9. How does RST compare in performance with single crystal and mechanically alloyed products?

- It is recommended that valid comparisons be made for competing air foil technologies. The tests could include: LCF, creep, oxidation, cooling effectiveness, corrosion, coating compatibility, transverse strength and ductility, and repairability.

- It is recommended that NMAB do an equivalent study (to the RS superalloy disk applications) on blades and vanes, and include the comparisons noted above.

- We should consider RST for those applications where specific advantages of the technology can be exploited.

10. What is the potential of RST for substitution of critical/strategic materials?

- This potential has yet to be clearly defined on a scientific basis. RST is not a panacea technology.

- A possible potential of RST may be in manufacturing of composite components (using plasma or laser deposition) in which critical elements are only used in needed areas.

11. What are the strengths and limitations of the various consolidation processes that are used for RS superalloy powders?

- The microstructures of RS powders are affected by consolidation processes. This issue should be addressed in considerable depth.

PROGRAM

July 1-2, 1981

BRIEFING	**Wednesday, July 1**
8:30 a.m.	Registration
9:30 a.m.	WELCOME — E. Ambler, Director, NBS, U.S. Department of Commerce
9:40 a.m.	INTRODUCTION — J. S. Kane, Associate Director for Basic Energy Sciences, DOE
9:55 a.m.	DoD MANAGEMENT OF TECHNOLOGY BASE PROGRAMS — G. P. Millburn, Acting Deputy Under Secretary of Defense for Research and Engineering, Pentagon
10:25 a.m.	Coffee Break
10:45 a.m.	GOVERNMENT-WIDE IMPLEMENTATION STRATEGY FOR RST — J. Persh, Staff Specialist for Materials and Structures, OSD/OUSD R&E (ET), Pentagon
	Session Chairman — J. Persh
11:00 a.m.	RAPID SOLIDIFICATION METHODS AND GENERIC PROGRAMS — R. Mehrabian, Chief, Metallurgy Division, NBS, U.S. Department of Commerce
11:30 a.m.	LIGHT ALLOYS PROGRAM — H. M. Burte, Chief, Materials and Ceramics Division Materials Laboratory, AFWAL/MLL, Wright-Patterson AFB
12:30 p.m.	FERROUS ALLOYS PROGRAM — E. S. Wright, Director, Army Materials and Mechanics Research Center, Watertown
1:00 p.m.	Lunch
2:00 p.m.	SPECIALTY MATERIALS (INCLUDING METALLIC GLASSES) PROGRAM — R. Schmidt, Administrator, Materials Technology, Naval Air Systems Command
2:30 p.m.	SUPERALLOYS PROGRAM — E. C. van Reuth, Deputy Director for Materials Sciences, DARPA
3:30 p.m.	Coffee Break
3:45 p.m.	INTRODUCTION TO WORKSHOP FORMAT — L. A. Harris, Manager, Materials and Structures, OAST, NASA
4:00 p.m.	Divison of attendees into three Working Groups: Light Alloys, Ferrous and Specialty Materials, and Superalloys. Discussion by the Moderators of the questions to be addressed in the Workshop on the following day. Input from the participants for other items of importance for the Workshop agenda will also be sought.
5:30 p.m.	ADJOURN

EVENING PROGRAM — Washingtonian Motel

6:30 p.m.	Cocktails
7:00 p.m.	Banquet
8:00 p.m.	KEYNOTE SPEECH — Dr. Arden L. Bement, Vice President for Technical Resources, TRW, Inc.

WORKSHOP Thursday, July 2

9:00 a.m. Assemble as Working Groups into specific Workshops. The general format will be as follows:

Each Group will have two or three Moderators, and two Recorders, see list attached.

The Moderators will have previously apportioned the available time into the number of questions to be addressed, discussed, and debated. An assigned speaker will kick off the discussion with a five- to ten-minute presentation, thus opening avenues for discussion. At the end of the apportioned time for that question, the Moderators will end the discussion and move on to a new subject.

It is anticipated that during the morning session at least four to five subjects would have been addressed with a 15-minute coffee break at 10:30 a.m.

1:00 p.m. Lunch

2:00 p.m. Workshops

3:45 p.m. Coffee Break

4:00 p.m. Report of the Workshop Findings to all attendees in a Joint Final Session.

One Moderator from each Workshop Group will report its findings to all attendees in 15 minutes and an additional 15 minutes will be allowed for discussion.

5:30 p.m. ADJOURN

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15. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The aim of this Briefing/Workshop was to first provide the private sector with the government-wide implementation strategy for Rapid Solidification Technology (RST) in the next five years; and second, to seek industry/university input and involvement in order to effect a wider range of applications of this technology - based "breakthrough".

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Ferrous and specialty materials; light alloys; metallic glass; rapid solidification; workshop

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