SUPERALLOYS - DOES LIFE RENEW AT 50?

Reviewing Our Resources: minerals, capital, applications, organizations, technical knowledge, people, ideas + faith.

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Superalloys! How easy it is to personify them, to attribute to them the virtues that we would admire in a venerable friend - stability, toughness, strength, and adaption to the environment, a "thick" skin (see Table 1).

Table 1
Virtues of Superalloys

<u>Virtue</u>	<u>Technical Manifestation</u>
Stability-----	γ' stability without TCP phases
Toughness-----	High fracture toughness
Strength-----	Creep-fatigue resistance to 2100 ^o F
Adaption to Environment-----	SCC, H ₂ resistance
"Thick Skin"-----	Impervious Cr ₂ O ₃ , Al ₂ O ₃ surface films

Most admirably, they have thrived on knowledge, thus demonstrating continued growth in ability through their first fifty years (see Fig. 1).

But, are they resourceful? Will their growth continue?
Does life renew at 50?

Let's examine their basic resources in a management systems sense as in Fig. 2. Materials, plant, equipment, energy, capital, existing knowledge and real people are these resources. We manage these to produce superalloys for application. In the process we gain new ideas (alloys and processes), new people, new capital, and save energy and scrap. All these can be recycled as new resources. I shall

Fig. 1 Progress in the Temperature Capability of Superalloys in the Last 40 Years

Fig. 2 Management System for Superalloys

comment on the renewal process on each resource.

I RENEWAL OF KNOWLEDGE RESOURCES WITH NEW IDEAS

There is little hazard in hypothesizing that superalloys, of all our materials, have progressed the most from enlightened knowledge. We can revel in the power of understanding that we have gained in phase stability, γ' strengthening mechanisms and surface stability! But can we find comfort in the renewal of that knowledge base with novel ideas?

A. Literature & Patents

One measure of this base is the number of literature citations. Although the trend over the last decade is up markedly in both nickel and cobalt base alloys (see Fig. 3), citations have dropped 20% since Seven Springs III in 1976. In that latter period, nickel-base citations on (a) heat treatment have doubled, (b) melting and refining have doubled, (c) forging and rolling have held steady, and, (d) powder metallurgy have dropped a surprising 27%. Any concern I might have about the recent trend is moderated by the very growth in submitted papers and attendance at this traditional Seven Springs Conference. After all, the number of papers/ton of alloy sales still must be the highest of any base metal system.

As to quality of new knowledge, one rigorous measure of novelty is the number of patent grants because the patent system is designed to screen novelty critically. Examining this criterion of progress (see Fig. 4), we note significant growth from 1965 to 1971, but no growth since then. Invention may not be keeping pace with growth of the industry and this may haunt us in five to ten years.

The proportion of grants of non-U.S. origin has grown, from 26% of total grants for 1965-76, to 30% of total grants for 1977-78. This trend, along with the listing of the countries of origin of patents and participation at this meeting (see Table 2) remind us of a major change. Our superalloy friend has become very cosmopolitan. Knowledge of superalloys is widely dispersed over our earth, in an expanding universe of active organizations.

Fig. 3 Nickel and Cobalt Base Alloys — Literature Citations

Fig. 4. Nickel and Cobalt Alloys — Patent Grants by U.S. Patent Office

Table 2
International Participation in Superalloys

<u>Country</u>	<u>Patent Grants in U.S. 1965-1978</u>	<u>Papers at Seven Springs IV</u>
Australia	1	1
Austria	3	-
Belgium	4	1
Canada	4	-
France	17	3
Germany	26	2
Japan	72	2
Netherlands	6	1(Chairman)
Norway	1	-
PRC	-	10
Sweden	-	1
Switzerland	3	-
U.K.	61	7
U.S.S.R.	6	-

B. Recent Papers

More detailed analysis of papers at Seven Springs IV (see Table 3) reveals that process development reigns as the major new idea topic. For many years, superalloys and process inventions have enjoyed a "symbiotic" relationship.

Table 3
Technical Topics of Seven Springs IV Papers

<u>Technical Topic</u>	<u>No. of Papers</u>
Processing	22
Alloy Design	16
γ' Strengthening Mechanism	1
TCP Phase Stability	2
Carbides, Inclusions, Oxides	11
Trace Elements & Grain Boundaries	4
Fatigue or Creep-Fatigue	8
Surface Stability	7
Grain Size, Orientation & Shape	12
Strategic Elements & Conservation	6

In Table 4, witness the long string of success stories of processes that were piloted with superalloys. Several of these processes, of course, have since been used in commerce for years in a broad range of other alloy systems. The recent progress on powder atomization, mechanical alloying, Hipping, superplastic forming/diffusion bonding and laser treatment is testimony to lively renewal. Furthermore, we should realize that paper and patent statistics underestimate this renewal of process invention. Whereas alloy ideas tend to be published and patented, process ideas often are guarded as know-how. Truly, the 1970's was a decade of process revolution for superalloys.

Table 4
Process Inventions Piloted With Superalloys

- Vacuum-Induction Melting
- Vacuum-Arc Melting
- Electroflux Melting
- Investment Casting
- Isothermal Forming
- Directional Solidification
- Coatings
- Powder Atomization
- Mechanical Alloying
- Hipping
- Superplastic Forming/Diffusion Bonding
- Laser Treatment

It is encouraging to see in Table 3 that alloy design is not dead, contrary to rumor. A rejuvenation has been spurred by strategic element problems, and as a spin-off afforded by and optimized for new processes.

By 1970, our empiricism was highly enlightened in γ' strengthening mechanisms. It is not surprising that only one paper on that topic will be presented here. On phase stability, the major enlightening contributions of Phacomp in the 1960's had been supplemented by computational refinements in the 1970's and, in fact, is the subject for but two contributions at this conference.

The understanding of the control of carbides is still evolutionary. At least two papers will address this problem. If we broaden this topic to other non-metallics such as carbide fibers, inclusions and oxides, an additional nine papers signal lively interest in this technology.

Stabilization of grain boundaries, especially under creep-fatigue regimes and at surfaces, has attracted primary mechanistic attention. Nineteen(19) papers address various factors related to these topics including trace elements. Grain size, orientation (texture) and shape were topics of very significant advance in the late 1960's and early 1970's. Technological progress on these topics continues, witness 12 papers to come.

Lastly, a spurt of activity has been generated in strategic elements, conservation and recycling by recent deep-seated resource and economic problems.

On balance, I conclude that the renewal of the knowledge resource of superalloys was ample early in the decade but is somewhat questionable over the recent past!

II OUR MATERIAL RESOURCES

A. Chronic Scarcity

We experienced pervasive shortages in alloying additions for superalloys during the periods 1973-74 and 1979. These two periods of general shortages were unique to the 33 year period between 1946 and 1979, in contrast to the period from 1953 through the mid-60's when production capacity exceeded demand. One might ask if these two recent crises were a signal of a basic depletion or inadequacy of national resources. In contrast to the oil case, the evidence negates any such limit to growth. If anything, our mineral reserves are increasing. Rather, the 1973-74 crisis derived from a lack of investment in capacity expansion because of: 1) deterioration in corporate profits after 1966, 2) record high interest rates of the late 60's and 3) reduction in capacity utilization between 1970 and 1972. Investment spending did increase in 1973-74 as the economy expanded but with the notable exception of nickel, the recession of 1975 caused many projects to be cancelled or delayed. These root causes are exacerbated in 1980, witness the inflation in our alloying costs (see Table 5).

Table 5
Element Usage & Cost in Superalloys

Element	Usage in Superalloys As % of Total Usage of Element	Cost of Element		
		1976 \$/lb.	1980 \$/lb.	1980/1976 Ratio
Ni	7	2.25	3.20	1.4
Cr	3	2.44	3.69	1.5
Co	22	4.20	25.00	5.9
Mo	5	7.00	13.80	1.9
Al	1	0.41	0.70	1.7
Ti	5	2.50	8.80	3.5
Cb		36.00	55.80	1.5
Ta		42.00	90.00	2.1
W	3	9.80	14.00	1.4
Inflation Rate		5%	13%	2.6
Oil Price/Barrel		12.00	24.00	2.0

B. Critical Disruption of Supply

Even more troublesome is the prospect of sudden disruption of supply of critical elements, such as the recent case of cobalt.

Which elements should receive priority attention?

A useful approach is suggested with the Critical Minerals Index (CMI). (1) The CMI ranks relative criticality of minerals by simultaneously considering: a) the likelihood that the market for each mineral will be disrupted during a specified future time period because of political, military or economic events, b) the resultant cost if such a disruption were to occur, and c) the substitutability for the element by other elements. The CMI data of Fig. 5 illustrate the criticalities of cobalt over the next five years. The progress in (a) deriving cobalt from dispersed geographic sites and (b) in finding substitutes will diminish its CMI.

Another approach is Hannon & Penner's Economic Importance (EI) Index which takes into account, for a given element: (2)

- a. the number of possible applications for the good
- b. its scarcity (annual percent depletion, political availability)
- c. the number of possible substitutes and
- d. their scarcity.

It is ironic that chromium has not received attention in either of the above studies. Its ore and production are highly localized in regions of potential disruption, and its applications are many and of very high economic value. It is the source of the tight, adherent, impervious Cr_2O_3 film that protects superalloys and stainless alloys from aqueous, gaseous and salt corrosion. Over 50 years of research have failed to find a substitute for chromium and its mechanism.

Chromium must be rated at the top of the priority list! It is incumbent on us to address policy and tactics to ward off a crisis with chromium. More widely dispersed mineral sites should be located. The technological search for substitutes should be unrelenting, despite the frustration of such attempts to date. We will hear tomorrow of technology

Fig. 5 Critical Minerals Index for Cobalt (1)

for recycling chromium. It is prudent to have such technology on the shelf, piloted and ready as a contingency tactic.

III OUR CAPITAL RESOURCES

Investment in New Processes, In Plant and Equipment for Superalloys

The tradition of our organizations has been to reinvest capital in the new processes of Table 4 to the benefit of quality and quantity of superalloys. But the hazards of such capital injection seem so acute at this time that this looms as another critical renewal problem. For example, take today's overcapacity problem in P/M atomized superalloys. With runaway inflation and slow developing markets, how do we cope with such investments? Is retardation of technological progress our fate?

No easy solutions are forthcoming. In fact, it never has been easy to return one's investment.

Let's look at a recent survey by Biggadike on 68 case histories from the Fortune 500 companies, on widely variant new businesses in existing markets (see Table 6).(3) The

Table 6
Results of 68 Ventures Launched
by Fortune 500 Companies (3)

- A. Median Performance
 - 8 years before they reach profitability
 - 8 years to reach positive cash flow
 - 10 to 12 years to reach ROI of 17%
- B. The Eventual Winners
 - Built high market share
 - But sacrificed early profits for share building (suffered more negative 1-4 year ROI, cash flow)
 - Built capacity ahead of demand.

"The biggest risk is entering too small"

successful ventures were characterized by tactics of rapid capture of market share by early capital investment to build capacity ahead of demand. These tactics required sacrifice of early profits, with positive cash flow delayed eight years and attainment of ROI targets delayed 12 years. The losers were too cautious. In trying to profit too early, they put "one toe in the water" adding insufficient capacity to keep ahead of demand. Thus, the P/M atomized superalloy problem is rather typical of the fraternity of new business winners, at the same stage of life. It seems that if we are to seek continued technological growth of superalloys, we must heed Biggadike's conclusion that in corporate venturing as in love, "Faint heart never won fair lady." That means faith, patience and belief in the necessity for renewal. Further it means mustering all of our intuitive skills in picking the winners.

IV APPLICATIONS & MARKETS

Superalloy applications are listed in Table 7. Aerospace and gas turbine uses still dominate the market with over 90% of the total.

Table 7
Applications of Superalloys in U.S.

<u>Application</u>	<u>Percent of Total Use</u>
Aerospace	
Gas Turbines	73
Air Frames	8
Power Generation	
Gas Turbines	10
Nuclear	2
Fossil	1
Chemical Process	6
Miscellaneous (Including:	
Transportation, Marine, Pollution Control, etc.)	1

The current U.S. consumption is ~ 100 million pounds per year. A growth rate of 6% annually over the next five years is predicted for the U.S. Even greater growth is foreseen internationally, resulting from a structural change in marketing. World-wide engine orders will call for technology transfer to and manufacturing steps in the user country.

One must question, however, the longer range business cycle resistance of an industry based so heavily on one application. Promise is seen for diversification outside the aerospace market, especially in automotive turbochargers and in deep oil, gas and geothermal well goods. Development of these and other new high growth markets should receive close attention in the early 1980's.

V SUPPLY ECONOMICS

Renewal of the Supply Side in the 1980's

Most basic to the above material, capital resource and market problems is inflation. The Industrial Research Institute(IRI), in a position statement on government economic policy to stimulate innovation, urges a coordinated positive government action to control the basic causes of inflation.(4) Such action is essential to unshackling industrial innovation. The IRI notes that: "Because accelerating inflation adds to the investment costs required and because the uncertainty of the true value (i.e., in deflated dollars) of the expected return is increased, inflation shortens the time and risk horizons of both entrepreneurs and management groups responsible for innovation decisions to the point where both number and quality of innovation attempts, especially in high-technology areas, are severely reduced."

Professor H. Fels of the University of Kiel, Germany, has stated that: "Keynesian policies had their chance but they did not succeed." What is now required is a strategy based on supply rather than demand.(5) Badini pointed out that the tightened physical and monetary policies of recent times have encroached more on real output than on inflation.(6) As a result, we have seen reduced availability, shortages, excessive depletion, increase in costs of new materials and basic commodities. Janssen emphasized that concentration on monetary policy and management of aggregate demand has aggravated stagflation.(7)

Many economists and the IRI have redirected their attention to various incentives for increasing the rate of capital formation including modification of progressive income taxes, decreased tax on capital gains and accelerated depreciation allowances.

Fels' ideas lead us in another direction. He argues more for structural changes in industry than for taxation changes. Both Janssen's and his thoughts imply that our continual recent drive for cost reduction in existing processes has been quite inefficient in solving stagflation and in increasing growth and jobs. Fels states that the answer lies rather in innovation of both products and production processes to create new markets for themselves. (The hand calculator is an example of such a surprise in the marketplace, creating an entire new growth industry led by surprising consumer demand.) Fels finishes by asking: "Which will be the growth sectors of the future?" He admits that economic science has no answer and concludes by stating that: "Seeking out new opportunities for growth is primarily a matter for industrialists themselves." Superalloy technologists -- that's the challenge that we face and should solve in the 1980's.

VI ENERGY RESOURCES, ANOTHER CHALLENGE OF THE 1980's

Could there be a more crucial question than whether we have optimized the net energy benefit of superalloys?

In figurative and literal senses, superalloys are energy. For example, they can be substituted for energy if service temperatures or pressures can be raised to increase process, turbine and engine efficiencies. They could help open the supply of alternate energy sources to oil such as HTGR, deep gas wells, geothermal wells, and coal gasification. All these are energy savings that "renew" the resources of Fig. 2.

On the other hand, superalloys have avaricious appetites for energy during birth (see Table 8). The alloying constituents require high energy for mining and concentration of ores and also for reduction of refractory ores and intermediate compounds. The steps of alloying are sometimes multiple and the batch sizes are small. Their greatest virtue in service, hot strength, dictates that intense thermal and mechanical energies be used in hot shaping. Solution treatments above the service temperature are often specified and followed by complex, long aging treatments.

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Herein are ample challenges for the 1980's for superalloy innovators! One wonders to what extent we can diet by:

- a. Improving yields in steps 3 and 4.
- b. Recycling scrap to steps 2 and 3.
- c. Speeding kinetics of metallurgical process of hotworking and consolidation.
- d. Perfecting casting, Hipping and hotworking to net shape.
- e. Incorporating microstructural design and control into casting, Hipping, hotworking and cooling to obviate the need for subsequent solution treatment and aging.
- f. Using microprocessors to attain c. and e., based on the knowledge of isothermal and athermal grain and phase transformations.

Furthermore, what new energy can be delivered through structural innovations that extend life at high thermal efficiencies? Can we redesign grain boundaries at superalloy surfaces to be stable and stronger in the face of creep-fatigue and the encroachment of environmental contaminants? Can we invent impervious coatings that upgrade creep-fatigue resistance?

VII SUPERALLOY RENEWAL PROBLEMS AND SUPERALLOY PEOPLE

In summarizing the outlook on our resources, we are renewed amply with active organizations and aerospace applications. It is questionable that the knowledge base is so renewed in very recent years. Further, we must face renewal problems such as:

- a. chronic scarcity and critical disruption of alloying element supply
- b. general stagflation
- c. lagging capital investment in new processes
- d. lack of diversified markets
- e. inflating energy costs for processing
- f. limitations on applications because of creep-fatigue and surface instability.

The ultimate resources to be rallied are our superalloy people and organizations! Many in this audience have practiced superalloy metallurgy for over 20 years, at the bench in marketing and in management. Their experience and intuitive skills are sharpened by enlightened empiricism. New people with powerful theoretical insight have formed the team. These newcomers teathed on superalloys, since these alloys have been very popular for academic studies using powerful new instruments.

Our organizational structure is well positioned with:

- a. a diversity of international industrial, governmental and academic organizations with competitive technology and marketing
- b. linked by technical information exchange through this powerful Seven Springs International Conference.

Finally, I will speak to technological philosophy as it relates to deployment of our people, the richest resource that we have enjoyed in these 50 years. I favor the philosophy of René Dubos, that "trend is not destiny." When faced with need and sufficient freedom, people are marvelously efficient in their capacity to shatter trends, to cut the Gordian knot. On freedom, I follow Norman Cousins, who stated, "The only safe assumption for human beings is that the world will be what we make it our dreams and not our predictions are the great energizers." It is that faith that animates superalloy people.

Dedication: To the late Professor J. W. Freeman who led me to superalloys, my first technology love, and to C. G. Bieber.

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