solution. We would, however, like to make the following comments on his analysis:

(1) He maintains that the flux conservation condition $j_a/j_b = \alpha/\beta$ applies to all points in the metal matrix. Although for purposes of conservation of stoichiometry the above is plausible at the interfaces, it is not immediately obvious why this should apply everywhere in the bulk: indeed, in this situation, we suggest that the appropriate condition is

$$\frac{j_a}{j_b} = \frac{C_a\,(\text{bulk})}{C_b\,(\text{bulk})}$$

(2) It is not clear how relations derived from the Gibbs-Thompson equation, and which strictly apply to interface phenomena, can be substituted in his equations 4 and 5 which refer to the bulk.

Finally, we agree with his misgivings concerning the application of the principle of minimum entropy production in the interpretation of mass transport kinetics in such complex systems, and indeed, this was the reason why we hesitated to analyse our results along these lines.

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Wrought Cobalt-Chromium Surgical Implant Alloys

The two most popular alloys now used for the repair or replacement of damaged bone in human patients are molybdenum-containing wrought austenitic stainless steel and precision cast cobalt-chromium-molybdenum-carbon alloys [1]. Unfortunately, neither of the above alloy systems can be regarded as ideally suitable implant material. Stainless steel tends to pit and crevice corrode in body fluids [2, 3], while precision cast cobalt-chromium-molybdenum-carbon alloys such as Vitallium, Vinertia, Haynes Stellite 21, etc., possess insufficient ductility to withstand short-comings in design, fabrication or use [4]. The stronger and more ductile wrought Co-Cr-W-Ni alloy Haynes Stellite 25, sometimes used in conjunction with, or as a replacement for cast HS 21, although vastly more resistant to crevice corrosion than stainless steel, has been found inferior to cast Vitallium [5, 6] (HS 21, Vinertia, etc.). Crevice corrosion of this alloy has also been found to lead to corrosion fatigue failure [7].

In our studies of the hot and cold deformability of Co-Cr-Mo-C alloys of varying composition we have found that the mechanical properties of a number of such cast alloys if hot worked either by extrusion or press forging at 1100 to 1200°C can be improved. By subsequent heat-treatment it was found possible to more than double the as-cast percentage elongation. Such an increase in ductility permitted cold reductions of 35% (RA) by cold swaging and about 26% by cold rolling. The same techniques were used to improve the mechanical properties of as-cast HS 21 as shown in table I.

Orthodox electrochemical measurements [8] such as critical potential, resting potential versus time, and corrosion current density versus time at passive potentials were carried out in isotonic salt solutions and in such of higher chloride and hydrogen ion content [9]. Since such measurements are but of limited usefulness in assessing crevice corrosion resistance [10] of alloys, accelerated crevice corrosion tests in a 10% HCl plus 1% $FeCl_3$ solution at 37°C were also made. These accurately machined and finely finished alloy specimens tightly fitted with accurately machined and finished teflon washers, were compared with non-gasketed samples of the same alloys. Gasketed samples of Mo stainless steel in this solution were found to exhibit visible evidence of crevice corrosion in the first hour after immersion, wrought HS 25 specimens in four to six days, cast HS 21 specimens in not less than fourteen days. The corrosion rates listed in table II indicate crevice corrosion was not observed in the wrought and heat-treated specimens of HS 21 in four weeks.

The superior mechanical properties, as well as corrosion resistance of the wrought HS 21 alloy as compared to the cast alloy of the same composition can be attributed to the more homogenised finer grained matrix structure and more uniform distribution of carbides achieved by hot working and heat-treatment as indicated by the photomicrographs of figs. 1a and b.

TABLE I *Effect of processing on the mechanical properties of Haynes Stellite Alloy 21*

Treatment	Yield strength (psi)	Ultimate tensile strength (psi)	Elongation (%)	Reduction in area (%)	Rockwell -C hardness
Investment cast	82000	101000	8	9	30
Chill cast 3 in. diameter ingot; pressed forged and hot rolled at 1150°C	173000	194900	11	13	48
Chill cast 3 in. diameter ingot; press forged; hot rolled at 1150°C and heat treated*	108000	153000	18	15	38
Chill cast 1 in. diameter ingot; hot extruded at 1150°C and annealed at 1200°C for 4 h, quenched in water	85000	140000	17	14	32
Chill cast 1 in. diameter ingot; hot extruded at 1150°C and heat treated*	93500	155400	21	18	34

*Specimens were placed in a hot furnace at 650°C and the temperature was raised continuously for 1 h to 1050°C. The specimens were then held at 1050°C for 1 h and quenched in water.

TABLE II *Corrosion of implant alloys in 10% HCl plus 1% $FeCl_3$ aqueous solution at 37°C*

	Corrosion rates in g/cm²/day		Remarks
	Teflon-Gasketed samples	Non-gasketed samples	
Wrought and annealed 316L stainless steel	0·0210	0·0204	All samples severely pitted in first 2 h.
Wrought and annealed Haynes Stellite Alloy No. 25	0·0020	0·0002	Four samples crevice corroded in four days and five in six days.
As factory cast Haynes Stellite Alloy No. 21	0·0005	0·0000	Six samples crevice corroded in fourteen days and four in twenty-one days.
Factory cast HS 21, hot extruded and heat treated at 1050°C	0·00001	0·00000	No visible sign of crevice corrosion or etching in four weeks.

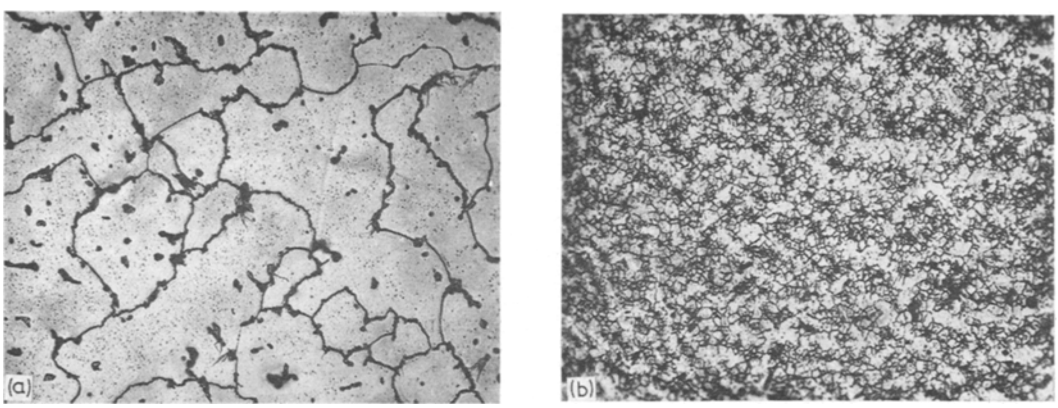

Figure 1 (a) Haynes Stellite 21. As precision cast. 5% HCl Electrolytic Etch. (×158). (b) Extruded at 1150°C and heated from 650°C to 1050°C in 1 h and held at 1050°C for 1 h followed by a water quench. 5% HCl Electrolytic Etch (×158).

The experimental results reported in this note clearly indicate that wrought and heat-treated HS 21 (and presumably Vitallium, Vinertia, etc.) could serve as a useful substitute for the wrought Co-Cr-W-Ni alloy HS 25 now used in some surgical implants, due to its adequate strength and ductility as well as its superior crevice corrosion resistance. Its higher tensile strength should make wrought HS 21 more acceptable from a fatigue standpoint and its higher hardness and microstructure from a wear standpoint than as-cast HS 21. To be sure wrought and heat-treated HS 21 is more difficult to cold form and machine than stainless steel, yet its vastly superior crevice corrosion resistance makes it a much safer, albeit more expensive, permanent implant material.

Acknowlegement

We are indebted to the National Science Foundation for financial sponsorship of the experimental work which led to this note.

References

1. "Proceedings and Reports of Councils and Associations", *J. Bone and Joint Surgery*, **53B** (1971) 341.
2. F. W. BULTITUDE and J. R. MORRIS, UKAE Authority Report GRO/44/83/22 (Ex.)
3. V. J. COLANGELO and N. D. GREENE, Report to National Institute of Health (GM-12661-01) (1968).
4. K. ASGAR and F. A. PEYTON, *J. Dental Res.* **40** (1961) 73.
5. G. ARNDT, T. M. DEVINE, and J. WULFF, "A New Cobalt-Chromium-Molybdenum-Wrought Alloy". Presented at the Fall Meeting of the *Metall. Soc. AIME* (1970).
6. J. WULFF and J. COHEN, *J. Bone and Joint Surgery* to be published.
7. R. M. ROSE, A. SCHILLER, and E. RADIN, *ibid*, to be published.
8. T. P. HOAR, and D. C. MEARS, *Proc. Roy. Soc. Lond.* **A294** (1966) 486.
9. P. WENDER, M.Sc. Thesis, M.I.T. Cambridge, Mass. (1971).
10. B. E. WILDE and E. WILLIAMS, *J. Electrochem. Soc.* **117** (1971) 1057.

Received 6 August
and accepted 3 September 1971

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Short Notice

Polymers in Space Research

Edited by C. L. Segal, M. Shen, and F. N. Kelley

Marcel Dekkar, $24.50 (£11·50)

This volume is based on the papers presented and discussed at the symposium on Polymers in Space Research held at the Western Regional Meeting of the American Chemical Society in Pasadena, California from 15 to 17 July 1968. It is divided into three sections: Recent developments in the synthesis, characterisation and evaluation of thermally stable polymers; properties of polymers at low temperatures; and solid propellants. The majority of the papers are written at a level intended for specialists in the field and give an indication of recent developments within these fields rather than an introduction to the topic as a whole. Furthermore, their emphasis is mainly on the phsycial and chemical aspects and, whilst this is to the advantage of the specialist scientific research worker, it makes them less useful for the technologist who wishes to aquaint himself with the information on polymers which has been generated by the needs of the space programme. Thus while it is possible to recommend this book to those who have a strong interest in one or more of the three major topics it covers, it is not, in the opinion of the reviewer, suitable for more general use.

D.A.W.

Mass Transport in Non-Metallic Solids

Proceedings of the British Ceramic Society, no. 19, March 1971.

This meeting was the third one organised by the Basic Science Division of the British Ceramic Society in the last seven years that has dealt with point defects and mass transport in non-