Laves phase in superalloy 718 weld metals

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The important consequence of the solidification in cast or welded superalloy 718 is the segregation of Nb and the formation of laves phase. Laves phase is a brittle intermetallic topologically close-packed phase with hexagonal structure, known for its detrimental effect on mechanical properties at room temperature [1]. Although data available with regard to wrought materials is somewhat elaborate it is not true for welds in general and for electron beam welds in particular. In this letter the formation of laves phase in high heat input gas tungsten arc (GTA) and low heat input electron beam (EB) welds of 2 mm thick superalloy 718 in as-welded and post-weld heat treated (PWHT) conditions is evaluated. The results have a bearing on the tensile ductility and other properties of welds.

Sheets of superalloy 718 of thickness 2 mm in solution treated condition (chemical composition in Table I) were autogenously welded by automatic GTA and EB welding processes, resulting in full penetration using the weld process parameters listed in Table II. The as-welded samples were subjected to two PWHT schedules: direct duplex ageing and solution treatment followed by ageing. Solution treatment was carried out at 980 °C for 20 min with air cooling and the duplex ageing was carried out at 720 °C for 8 h with furnace cooling to 620 °C for 8 h with air cooling. The as-welded and heat treated samples were then subjected to scanning electron microscopic (SEM) examination and quantitative electron probe micro-analysis (EPMA) for the analysis of microsegregation of elements and determination of the formation of laves phase.

Figs 1 and 2 show SEM micrographs of the as-welded microstructures of EB and GTA weld metals, respectively. Essentially, the solidified structure is of dendritic type. EB weld metal showed relatively finer

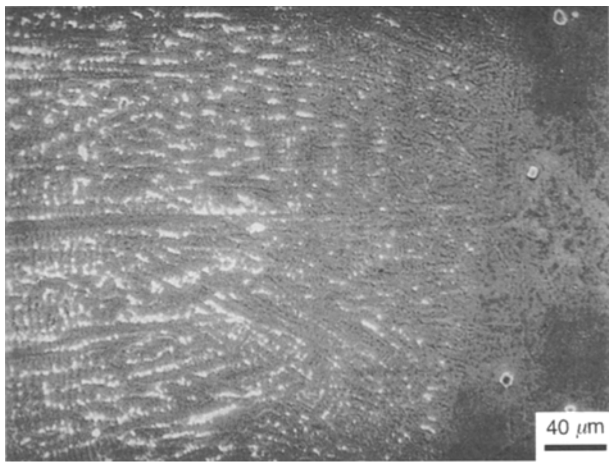

Figure 1 SEM micrograph of the EB weld metal in the as-welded condition.

TABLE I Chemical composition (wt %) of as-received base metal

C	Si	Mn	P	S	Cr	Ni	Mo	Ti	Al	Nb	Fe
0.04	0.08	0.07	0.005	0.002	18.45	54	2.95	0.98	0.45	5.15	Bl.
Nb+Ta	Co	Cu	B	Sn	Ag	Mg	Ca	Bi	Pb	O	N
5.15	0.001	0.002	0.004	<0.003	<0.003	0.003	0.005	<0.00005	<0.0002	0.004	0.005

TABLE II Details of GTA and EB welding parameters

Process detail	Automatic GTA	EB process
Voltage	12 V	120 kV
Current	70 A	9 mA
Welding speed (cm min^{-1})	20	150
Shielding	99.99% Argon	10^{-5} torr vacuum[a]
Working distance	2 mm (stand-off)	40 cm (gun-to-work)

[a]1 torr = 1.333 × 10^2 Pa.

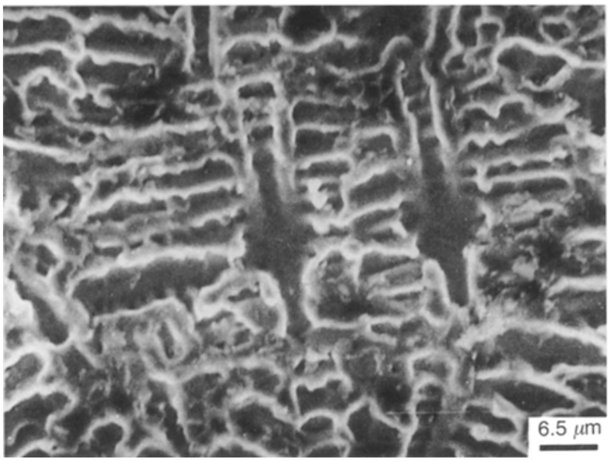

Figure 2 SEM micrograph of the GTA weld metal in the as-welded condition.

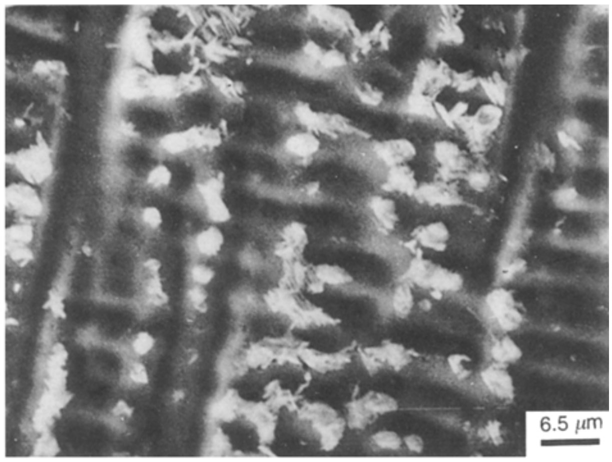

Figure 3 SEM micrograph of the GTA weld metal after solutionizing at 980 °C.

structure, as expected, than its GTA weld counterpart. The dendrites are attacked by the etchant and appeared as black depressions, while the interdendritic regions, which appeared relatively brighter, are unattacked. However, when weld metals are solutionized, the brighter regions in GTA weld metals show the tendency to globularize (Fig. 3). Incidentally, surrounding these globules, needle-like structures were also found to emerge. The needle-like phase is identified as delta phase (Ni, Nb) growing from the laves phase. Delta phase was also noticed by other researchers [2] in 718 welds after homogenization treatments at 954 °C. In contrast, in EB weld metals these bright spots were significantly less (Fig. 4). The dendritic structure was also found to be disturbed significantly, with secondary arms almost vanishing. In the case of GTA weld metal (Fig. 3), the primary as well as the secondary arms were still intact.

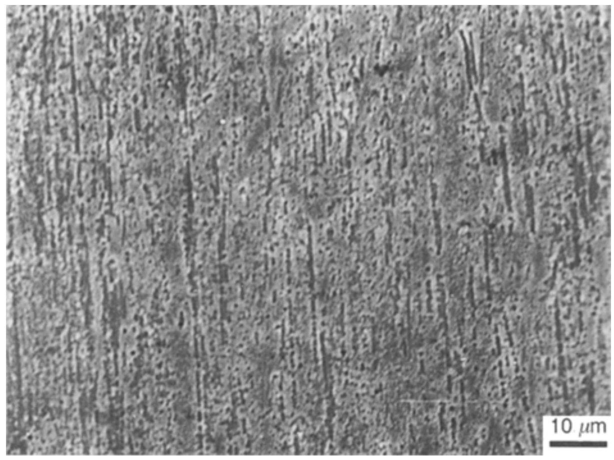

Figure 4 SEM micrograph of the EB weld metal after solutionizing at 980 °C.

In order to determine the nature of segregation in the welds, quantitative elemental distribution in the interdendritic and dendritic regions using scanning EPMA equipment was carried out. The results are presented in Table III and Table IV. It can be seen from the EPMA results that both the EB and GTA weld metals in as-welded condition exhibited Nb depleted matrix (Nb 2.5 and 2% respectively) compared to base metal matrix (Nb 5%). While the Nb content of the interdendritic regions in as-welded EB weld metal varied between 11 and 15%, it was maximum (20–22%) in GTA weld metal. Based on the composition, the Nb-rich areas in the interdendritic regions of the weld metal were identified as laves phase. Laves is a hexagonally close packed phase and is generally accepted [1] to be of the form $(Ni, Fe, Cr)_2$ (Nb, Mo and Ti). The EPMA results shown in Table III and Table IV support that the interdendritic regions enriched in Nb, Mo and Ti consist of laves phase. Incidentally, these regions are lower in Fe and Cr.

TABLE III Quantitative EPMA results of GTA welds

Sample history	Description of region	Element (wt %)						
		Ti	Nb	Ni	Cr	Fe	Mo	Si
As-welded	Weld-laves	1.692	20.018	46.820	14.857	14.356	3.381	0.165
	Weld-laves	1.426	21.714	45.883	14.298	14.235	3.832	0.207
	Weld-matrix	0.563	2.091	53.609	18.843	20.933	2.270	0.053
	Base metal[a]	0.868	4.961	52.649	17.066	19.752	2.659	0.058
As-welded + solution treated and aged	Weld-laves	2.194	20.710	43.704	15.105	14.686	2.755	0.055
	Weld-matrix	0.624	2.530	53.689	19.206	21.156	2.342	0.041
	Base metal	0.853	5.174	52.820	17.888	19.622	2.538	0.060

[a]Solution treated.

TABLE IV Quantitative EPMA results of EB welds

Sample history	Description of region	Element (wt %)						
		Ti	Nb	Ni	Cr	Fe	Mo	Si
As-welded	Weld-laves	1.266	11.329	50.762	17.501	17.385	2.989	0.136
	Weld-laves	1.465	15.347	49.521	16.084	15.564	3.220	0.144
	Weld-matrix	0.662	2.486	50.450	19.212	20.947	2.506	0.058
	Base metal[a]	0.923	4.621	52.367	18.426	19.837	2.714	0.044
As-welded +	Weld-laves	1.47	13.60	51.21	15.76	16.00	2.42	0.05
solution	Weld-laves	1.28	12.23	51.35	15.57	15.53	3.55	0.05
treated	Weld-matrix	0.87	4.51	52.49	19.16	20.43	2.70	0.07
and aged	Base metal	0.90	4.91	52.71	18.76	19.48	2.45	0.05

[a]Solution treated.

As for the effect of solutionizing, the EB weld metal responded relatively better to solution treatment, by redistributing Nb, than the GTA weld metal. It can be observed that GTA weld metal matrix was still depleted in Nb content (2.5%) compared to base metal (5.1%). Even after solution treatment, the interdendritic regions continued to show extensive Nb enrichment (21%). This indicates that the usual solution treatment (980 °C) applied is ineffective for GTA welds in homogenization of the weld structure and dissolution of its Nb enriched laves phase and may require higher solution treatment temperatures.

The presence of laves phase in 718 material is detrimental to its strength, tensile ductility etc. and hence is not desirable. Schirra *et al.* [1] reported mechanical property degradation in 718 alloy wrought material. They found a drastic decrease in room temperature ductility when laves phase was present as a continuous or semi-continuous grain boundary network. Laves phase can reduce the mechanical properties of 718 alloy through several mechanisms [1], the most dominant mechanism probably being brittle fracture of the phase. It also represents a weak zone microstructure where micro-cracks can initiate preferentially, leading to decohesion of laves phase/gamma matrix interface under the action of a tensile stress, leading to premature fracture. Secondly, the formation of the laves consumes large amounts of Nb, resulting in Nb depletion. Nb is a principal hardening element. Thirdly, it may result in microfissuring during welding, with the resultant pre-existing discontinuities.

In weld metals, the possibility of formation of laves phase appears to be largely due to micro-segregation of alloying elements because of non-equilibrium solidification of welds. Therefore, the weld coating rate is an important factor in controlling the formation of laves phase in weld metals. Although the cooling rate obtained by EB was relatively faster than that by GTA, laves phase still formed in the weld metals. However, the tendency for formation of laves phase in the weld metals was found to be greater with slower cooling rates, as in GTA. Therefore, from the point of view of controlling laves phase in 718 alloy weld metals, the lowest possible heat inputs should be used. In this regard, EB welding is found to be relatively better. Further, methods to extract the heat quickly from the welded region could be adopted. One practical method could be resorting to the use of chilling blocks in weld tooling, which can increase the weld cooling rates. Even in this regard, use of lower heat input processes like EB is advantageous because of the ease with which homogenization can be achieved even at lower solutionizing temperatures compared to higher heat input processes.

It also appears that the problem of laves phase could be controlled to some extent by reducing the Nb content in the weld metal. This could be achieved by using a filler (in the form of a shim) with similar composition to that of base metal but with relatively lower Nb content. Here it is pertinent to mention that 718 alloy cast materials with lower Nb content (4%) were found to be more readily homogenized, while those with more (5%) required extended homogenization treatments [3, 4].

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Received 23 January and accepted 2 May 1995