Superalloys 718, 625, 706 and Derivatives 2005 *Edited by E.A. Loria*
TMS (The Minerals, Metals & Materials Society), 2005

MECHANICAL PROPERTIES OF 718 INERTIA WELD AND ITS COMPARISON WITH EBW

P.V. Neminathan
Project Office (Materials),
Kaveri Engine Programme, DRDO,
Hyderabad, India

T. Mohandas
Defence Metallurgical Research Laboratory,
Hyderabad, India

Abstract

Nickel base superalloy-718 is extensively used in aero gas turbine for critical rotating assemblies such as discs and shafts. These assemblies are subjected to severe service conditions at high temperature. Some of the engine builders employ electron beam welding process for joining of these rotating assemblies. However, fusion welds of nickel base superalloys are prone to microfissuring in the heat affected zone. These defects arise due to solidification cracking as a result of liquation along the grain boundaries. This inherent metallurgical problem in EB welding process can adversely affect the mechanical properties, particularly fatigue. Solid state bonding processes, viz. Inertia friction welding, are known to mitigate this problem. Keeping this in view, inertia welding studies on this alloy were taken up. This paper reports mechanical properties of inertia weld of 718 alloy in addition to microstructural examination results. Effect of post weld ageing treatment is also incorporated. Microstructural examination revealed that the heat affected zone or weld zone are free from microfissures. The weld zone microstructure is much finer than the base metal. Tensile strength and dutility [at RT, 300°C and 650°C] as well as RT LCF lives obtained on inertia welds, in PWHT condition, were at par with the corresponding parent material in STA condition. A comparative study on EBW indicated that the tensile strength [at RT and 300°C] is comparable to that of parent material, but the ductility and LCF lives of EBW of 718 alloy were below that of the corresponding parent material.

Keywords : Inertia welding, Ni-base superalloy 718, Tensile properties, Microstructure, Post weld ageing, Grain size

Introduction

Nickel base superalloy 718 material is widely used in the gas turbine engine for aerospace applications. The material finds its extensive use for fabrication of critical rotating components of the engines, such as discs and shafts, which are subjected to severe service conditions at high temperature [520°C - 650°C]. Electron beam welding process is currently used for joining of these rotating assemblies. The fusion welds of the material are reported to be prone to microfissuring in the heat affected zone, which occur due to solidification cracking as a result of liquation along the grain boundaries. Inertia welding is a variant of friction welding process, in which joining occurs at a temperature below the melting point of the work metal. Therefore, the above mentioned solidification related defects at HAZ could be avoided if inertia welding process is adopted. In view of the above, an attempt was made to characterize the inertia welding of alloy 718 material. This paper present results of mechanical properties of inertia friction welded [IFW] samples and its comparative advantage over EB welded [EBW] samples.

Material

Nickel base superalloy 718 is a precipitation hardening alloy with an excellent high temperature strength. The alloy has relatively slow precipitation hardening characteristic and therefore, it can be weldable with relative ease without undergoing spontaneous hardening during heating or cooling. A hollow barstock of size 125mm OD x 101mm ID, sourced from M/s Inco Alloys International, UK, as per technical specification AMS-5663G has been used for the inertia welding trials. The actual chemical composition of the material is reported at Table-1. Pre-welding condition of the material was solution treated and aged [STA]. The pre-weld heat treatment cycles followed are as below :

Solution treatment : 980°C / hold for 3.5 hours / air cool.
Ageing : 720°C / hold for 8 hours / furnace cool at the rate of 55°C per hour to 620°C / hold for 8 hours / air cool.

Table – 1 : Chemical composition of the alloy 718 sample

Elements	Composition (in wt %)
Carbon	0.031
Silicon	0.09
Manganese	0.05
Phosphorous	0.006
Sulphur	< 0.001
Aluminium	0.50
Boron	0.004
Bismuth	< 0.1 ppm
Cobalt	0.14
Chromium	18.78
Copper	0.05
Molybdenum	2.95
Nickel	53.6
Lead	< 0.1 ppm
Titanium	1.02
Niobium + Tantalum	5.3
Iron	Balance

Process

In Inertia friction welding [IFW], one of the work pieces is clamped in a chuck/flywheel mounted on a rotating spindle and the other piece is clamped in a non-rotating fixture. The drive motor accelerates the rotation of the flywheel spindle assembly to a predetermined speed (energy level) and then the rotating drive power is disengaged. The parts to be welded are forced together and the kinetic energy of the freely rotating flywheel is rapidly converted to heat at the weld interface as axial pressure is applied. The rotation will stop, once the stored energy is exhausted. However, the forge pressure is maintained for a predetermined time even after rotation ceases, to complete the welding.

Weld parameters

The welding trials for this study were carried out on 272 tons class inertia welding machine at M/s MTI, USA. The weld parameters followed are as given below :

Sample size	-	125mm OD x 101mm ID x 100 Thickness
Size of flywheel	-	632 kg-m^2
Weld RPM	-	390
Axial load	-	167.5 tons.
Average upset obtained	-	5.15mm

Test results

Metallography :

The sample extracted from the interface of parent metal and weld and the inertia welding were subjected to microstructure evaluation. The microstructures are shown in Fig.-1 and Fig.2 respectively. From these micrographs, it is seen that the weldments are free from micro-cracks, porosity, etc.. No microfissures are observed at the heat affected zone. Since mechanical working is associated with inertia welding process, finer grain size is obtained in the weldment [ASTM 9-10] compared to its parent material [ASTM 4-5].

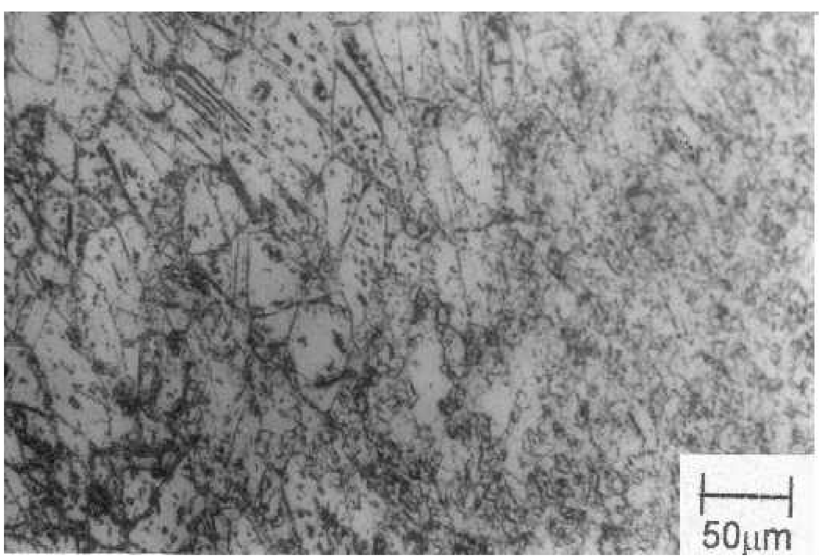


Fig. 1 : At interface of parent metal and inertia weld

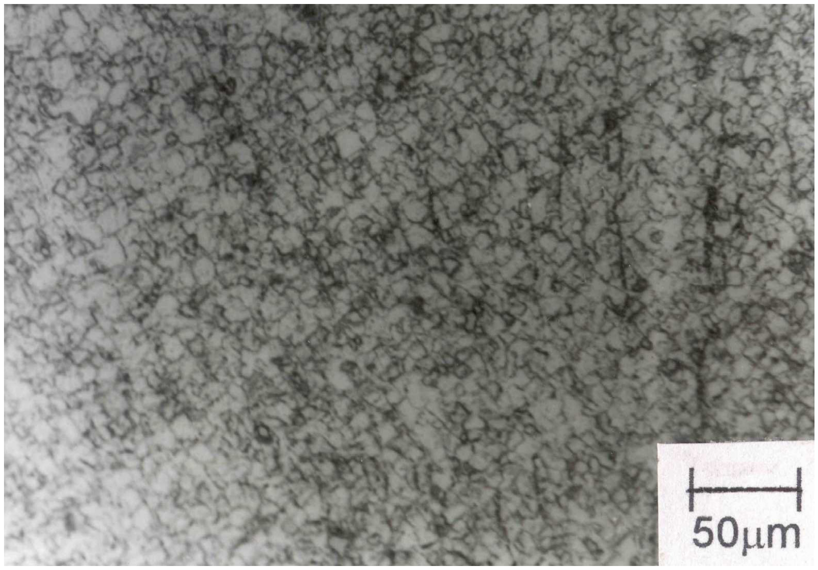


Fig.2 : At inertia weld

Tensile Tests :

Initially, the transverse weld tensile test specimens, in as-welded condition, were extracted. The tests were carried out at room and high temperature [300°C & 650°C]. The results obtained and their comparison with the material technical specification and parent metal are detailed at Table-2.

Table – *2*: Tensile properties in as-welded condition

Property	Specified (Min.)	Parent Metal		Inertia weld (as welded)	
				Sample-1	Sample-2
0.2% YS	1035 MPa	1124		614	648
UTS	1275 MPa	1378		957	992
% El. (4D)	12%	20		17	17
% RA	15%	36		61	53
0.2% YS	--	1102		551	563
UTS	--	1298		870	861
% El. (4D)	--	21		11	13
% RA	--	41		49	54
0.2% YS	860 MPa	972	903	623	654
UTS	1000 MPa	1156	1080	828	869
% El. (4D)	12%	17	21	17	12
% RA	15%	52	28	55	53

From the properties obtained, it was seen that the as-welded strength, both ultimate tensile strength and 0.2% yield strength, obtained were very low with respect to its parent material [STA condition]. However, these properties were comparable to the properties of 718 in ST condition [8]. This suggests that no precipitation of strengthening phases has occurred in the weld during cooling after the welding process. It is also observed that all samples invariably fail in the weld zone. Therefore, the weldments were subjected to a post-weld heat treatment [ageing]] to improve the strength. The heat treatment was carried out in a electrical heating furnace. The post-weld ageing cycle followed was as follows:

> "Load at 720°C / allow the furnace zone to re-attain the temperature / hold for 8.5 hours / furnace cool at the rate of 55°C per hour to 620°C / hold at 620°C for 8 hours / air cool".

Subsequent to post-weld treatment, the samples were subjected to tensile tests and the results are furnished at Table-3.

Table – 3: Tensile properties in post-weld treated (aged) condition
[Heat treated in electrical heating furnace]

Property	Specified (Minimum)	Parent Metal		Inertia weld		
				Sample-1	Sample-2	Sample-3
Room Temperature Tensile Properties :						
0.2% YS	1035 MPa	1124		1080	1161	1191
UTS	1275 MPa	1378		1373	1391	1369
% El. (4D)	12%	20		28	13	21
% RA	15%	36		28	31	38
High Temperature Tensile Properties At 300°C :						
0.2% YS	--	1102		990	1001	1074
UTS	--	1298		1248	1260	1263
% El. (4D)	--	21		19	17	21
% RA	--	41		44	45	42
High Temperature Tensile Properties At 650°C :						
0.2% YS	860 MPa	972	903	917	1007	924
UTS	1000 MPa	1156	1080	1101	1167	1110
% El. (4D)	12%	17	21	18	39	27
% RA	15%	52	28	27	65	53

In addition to the above, the post-weld ageing heat treatment was also carried out in vacuum furnace with the same heat treatment cycle except that the samples were gas fan quenched instead of air-cooled. This has been carried out to assess the influence of vacuum heat treatment, as the critical rotating assemblies of aero-gas turbine engines are subjected to post-weld heat treatment in vacuum.

Subsequent to this post-weld treatment, the samples, from both parent material and weldment, were subjected to tensile tests. The results are furnished at Table-4.

Table – 4: Tensile properties in post-weld treated (aged) condition [Heat treated in vacuum furnace]

Property	Specified for Parent metal (min.)	Parent Metal				Inertia weld (Post-weld aged)			
		1	2	3	4	1	2	3	4
Room Temperature Tensile Properties :									
0.2% YS	1035 MPa	1071	1063	1168	1122	1127	1157	1138	1192
UTS	1275 MPa	1351	1362	1394	1390	1384	1386	1388	1403
% El. (4D)	12%	23	26	24	24	14	12	16	13
% RA	15%	31	29	36	35	30	29	34	22
High Temperature Tensile Properties At 300°C :									
0.2% YS	--	983	928	1020	1009	964	1063	1044	1109
UTS	--	1238	1240	1301	1274	1243	1284	1283	1278
% El. (4D)	--	21	20	21	19	16	14	16	13
% RA	--	37	35	42	38	35	34	40	38
High Temperature Tensile Properties At 650°C :									
0.2% YS	860 MPa	895	885	972	903	866	908	951	971
UTS	1000 MPa	1104	1106	1151	1140	1128	1151	1185	1167
% El. (4D)	12%	23	20	28	28	19	12	24	16
% RA	15%	25	33	45	42	37	34	55	44

All the PWHT tensile samples were reported to be failing away from weldment suggesting that weld zone has been strengthened after PWHT as compared to the as-welded condition. From the results obtained, it was observed that the post weld ageing treatments, both in air and vacuum furnace, have improved the mechanical properties and their results are comparable. Room and high temperature [650°C] tensile properties of both parent material and inertia weld were meeting the minimum specified requirements. The tensile strength and ductility of the welds obtained, at both room and high temperatures [300°C and 650°C], were at par with the base metal.

Low Cycle Fatigue Test :

The samples from both parent metal and inertia weld were subjected to low cycle fatigue test, in vacuum PWHT condition, as per details given below :

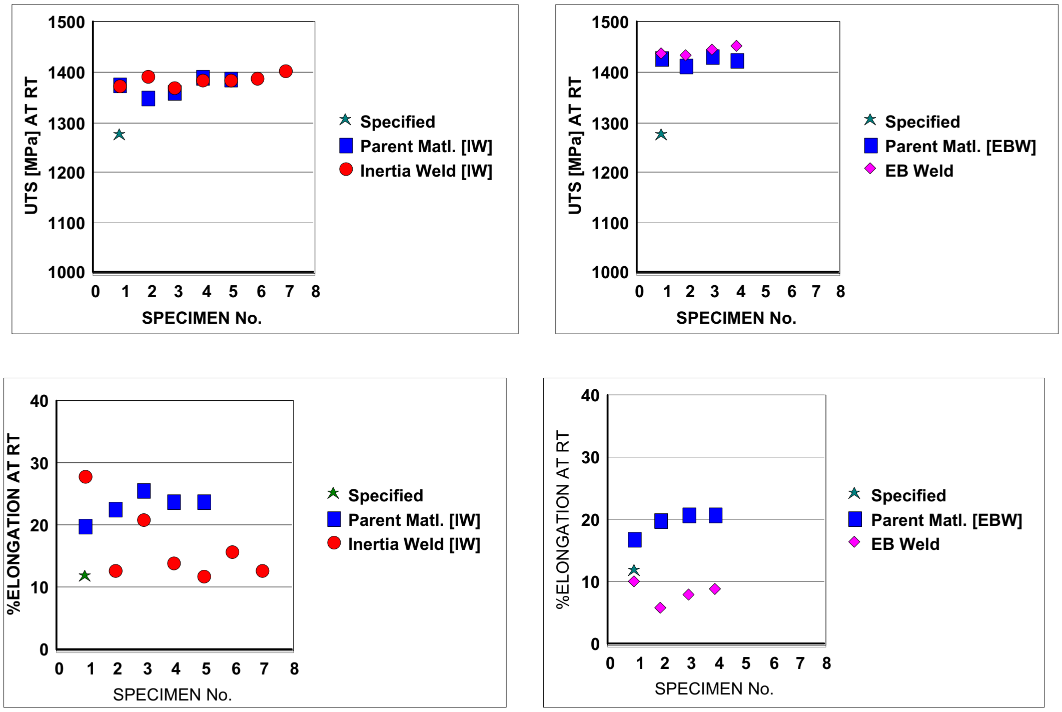
Temperature : Room temperature
Cycle of loading : Triangular
Axial stress applied : 9.5 MPa minimum to 950 MPa maximum
Frequency : 0.33 Hz

Property	Specified (Min.)	Parent Metal				Inertia weld (Post-weld aged)			
		1	2	3	4	1	2	3	4
Life	20000 Cycles	34797	37085	71328	51605	59267	30582	63650	46675

From the above results, one can see that room temperature LCF lives of both parent material and inertia weld are similar. No degradation in fatigue life has occurred due to inertia welding.

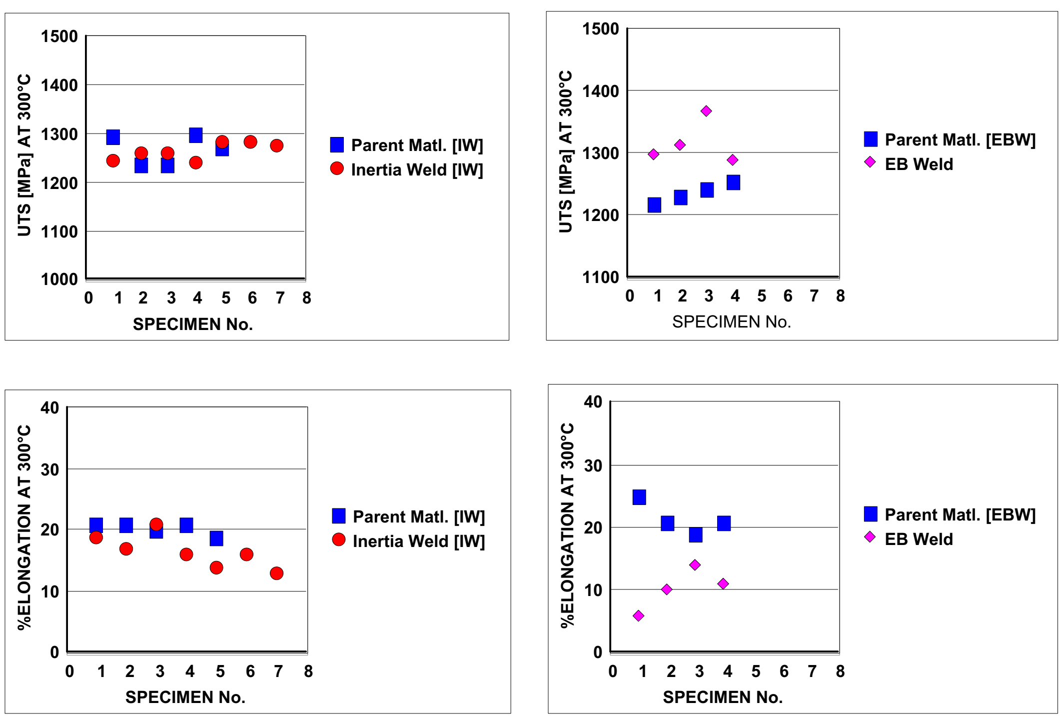
Comparative Assessment of IFW and EBW Samples :

Properties obtained on inertia welding are compared with EB weldment on 5mm thick – 718 alloy sheet from our earlier study [9]. In this study, mechanical tests were carried out on transverse weld specimens, in PWHTd condition. Since the parent material for inertia and EB welds are different, the comparison of these weld properties has been made with their corresponding parent material properties. Comparison of these processes is presented in Fig. 3, 4, 5 and 6.



INERTIA WELDING EB WELDING

Fig. 3 : UTS & %EL. of welds and their parent material at room temperature



INERTIA WELDING EB WELDING

Fig.4 : UTS & % EL. of welds and their parent material at 300°C

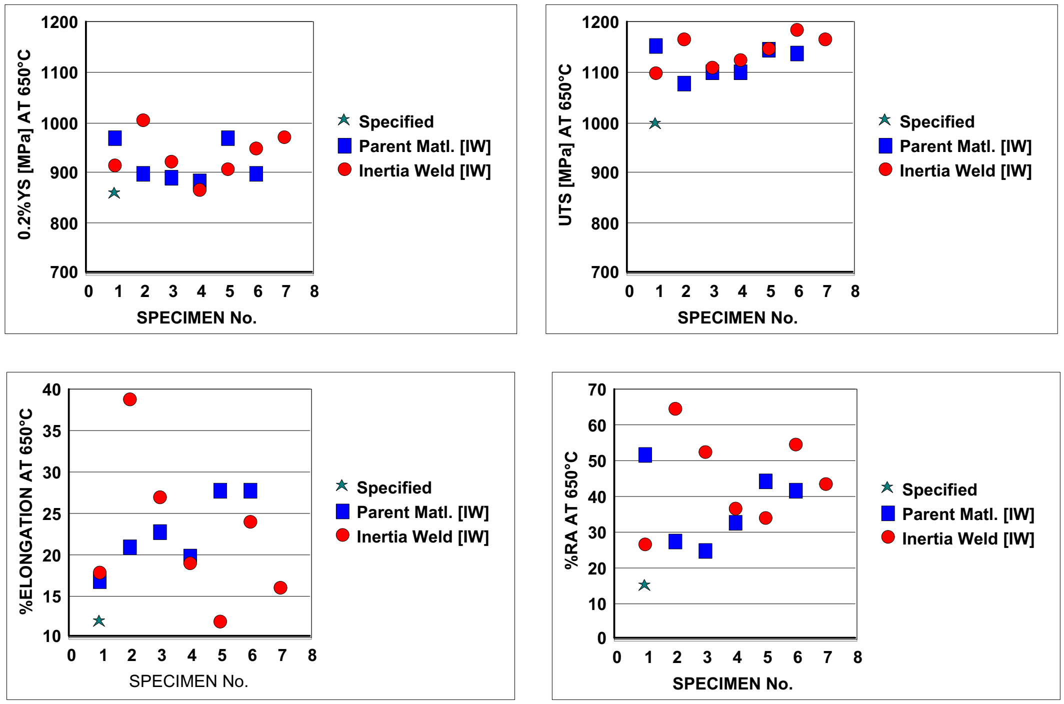
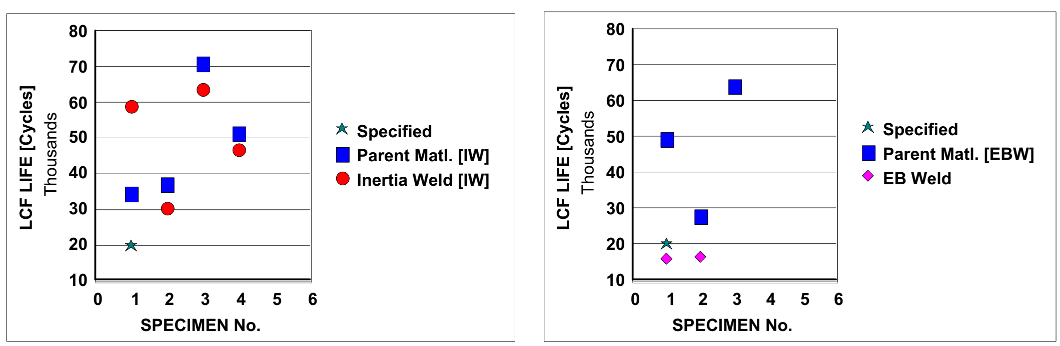


Fig.5 : YS, UTS, %EL. & %RA of inertia weld and its parent material at 650°C

LCF Test Parameter :

AXIAL STRESS APPLIED	:	9.5 MPa min. to 950 MPa max.
CYCLE OF LOADING	:	TRIANGULAR
FREQUENCY	:	0.33 Hz



INERTIA WELDING EB WELDING

Fig. 6 : LCF of welds and their parent material

From these figures, it is observed that the tensile strength and ductility [at RT, 300°C & 650°C] as well as LCF lives obtained on inertia welds are at par with the corresponding parent material in PWHT condition. In all the cases, the inertia weld specimens failed away from the weldment. However, in the case of EB weld, while tensile strength [at RT & 300°C] is comparable to that of the parent material, the ductility and LCF lives are lower than that of corresponding parent material. Moreover, the EB weld samples are also observed to fail at the weldments.

Conclusion

- In the as welded condition, the weld joints exhibited lower strength than the parent metal [STA condition].
- Post weld ageing treatment is necessary to retrieve mechanical properties of the inertia weld of alloy 718 at par with the parent metal [STA condition].
- Inertia weld zone grain size was finer than the starting parent metal grain size.
- Tensile strength and dutility [at RT, 300°C and 650°C] as well as RT LCF lives obtained on inertia welds, in PWHTd condition, were at par with the corresponding parent material in STA condition.
- Tensile ductility and LCF lives of inertia weld were better than that of EB weld.

Acknowledgements

The authors are grateful to the Defence Research and Development Organisation for funding this programme. They are also thankful to Mr. M Mohanan, Project Director [Retd.], Project Office (Materials), Hyderabad, and Dr. D Banerjee, CC R&D (AMS), DRDO, for their keen interest and encouragement to pursue the programme.

References

[1] E.G. Thomson, "Hot Cracking Studies of Alloy 718 Weld Heat-Affected Zone", Welding Research Supplement, WRC Bulletin, February 1969, pp. 70s-79s.

[2] M.J. Lucas, JR, and C.E. Jackson, "The Welded Heat-Affected Zone in Nickel Base Alloy 718", Welding Research Supplement, February 1970, pp. 46s-54s.

[3] R. Vincent, "Precipitation Around Welds in the Nickel Base Superalloy, Inconel 718", Acta metall 1985, Vol. 33, No.7, pp. 1205-1216.

[4] B. Radhakrishnan and R.G. Thompson, "Kinetics of Grain Growth in the Weld Heat-Affected Zone of Alloy 718", Metallurgical Transactions, Vol. 24A, December 1993.

[5] R. Nakkalil, N.L. Richards and M.C. Chaturvedi, "The Influence of Solidification Mode on Heat Affected Zone Microfissuring in a Nickel-Iron Base Superalloy", Acta metall 1993, Vol. 41, No.12, pp. 3381-3392.

[6] D.E. Spindler, "What Industry Needs to Know About Friction Welding", American Welding Journal, March 1994, pp. 37-42.

[7] E. David Nicholas, "Friction Processing Technologies", Advanced Materials & Processes, June 1999, pp. 69-71.

[8] Alloy Digest Data on "ALTEMP 718 ALLOY", published by Alloy Digest Inc, USA, January 1994.

[9] GTRE internal report "Test Results of Kaveri Engine (K4) LP Main Shaft EBW Certification Program" – No. GTRE\MAG\KAVERI\WELD\003 dated March '98.