Influence of thermal cycling on weldments of non-ferrous materials: I—Aluminium Alloy 6061

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SYNOPSIS

Argon arc welded sheets of Aluminium Alloy 6061, heat treated to T6 condition have been subjected to a number of thermal cycling (N), thermal amplitude ($A_T = 100°C$) in air, cycle duration (t) = one hour/cycle, and its influence on tensile strenght (σ), Hardness (H), elongation (e) as well as microstructures of the weldments were studied. The effect of thermal cycling is marked by a fall in σ, and e accompanied by slight rise in H up to about N=10 after which there is gradual tendency of σ, and e to increase, and H to decrease with further thermal cycling.

Microstructures of the thermally cycled weldments show the change in density of the initial (T6 condition) precipitates which grow thicker along with grain boundary fragmentation which continues from N=1 onwards.

The data thus obtained have relevance in designing satellite shell structure.

SINCE the study of "thermal" fatigue on materials is generally concerned with repeated heating and cooling of the alloy under mechanical constraint, very little is known about the effect of thermal cycling of unrestrained materials. The materials studied to-date subjected to such "thermal", or "thermomechanical" fatigue[1] do not include studies of precipitation hardenable alloys.[2] Although, recently some work has been undertaken on the thermal cycling of a duraluminium type material,[3] almost nothing is known about the effect of thermal cycling on weldments of 6061 aluminium alloy. Such studies will help in obtaining the design data concerning metallic shield to protect the main satellite structure made of plastics from radiation damage in space as well as from other relevant hazards when such scientific satellites are exposed once to the sunlit side and subsequently to very low temperature in the dark side during orbiting around the earth and are, consequently, subjected to thermal fatigue. The present study has been undertaken in order to find the effect of thermal cycling on mechanical properties of welded 6061 aluminium alloy.

Experimental procedure

The material for the above investigation i. e. the 6061-T6 Al alloy was obtained from M/s Hindustan Aluminium Corporation, and sheets of 2·3 mm thickness were arc welded under Argon atmosphere and then again subjected to T6 condition (solution treatments at 525°C for 20 minutes and ageing at 180°C for six hours). Then the specimens were machined in order to obtain uniform thickness and specimens for tensile and hardness tests were prepared. The chemical analysis of the weldment as compared with the standard composition of 6061 alloy is given in Table I, along with that of the "as-received" material.

These samples were subjected to thermal cycling in air with a thermal amplitude ($A_T = 100°C$ and cycle duration of t = 1 hour per cycle). Tensile strength (σ), and Hardness (H), were measured on samples subjected to the following thermal cycles N = 1, 2, 5, 10, 20 and 40 in a Universal testing machine, and Brinell

TABLE I Chemical analysis of the 'as-received' and welded samples of 6061-T6 aluminium alloy as compared with the standard alloy before welding

	Standard specification	'As-received'	Welded
Silicon	0·4 — 0·8%	0·7%	0·7%
Chromium	0·15 — 0·35%	0·23%	0·24%
Manganese	0·15%	0·14%	0·14%
Magnesium	0·8 — 1·2%	1·0%	0·97%
Iron	0·7%	0·66%	0·68%
Copper	0·15 — 0·4%	0·25%	0·25%
Zinc	0·25%	0·25%	0·24%
Titanium	0·15%	Nil	Nil

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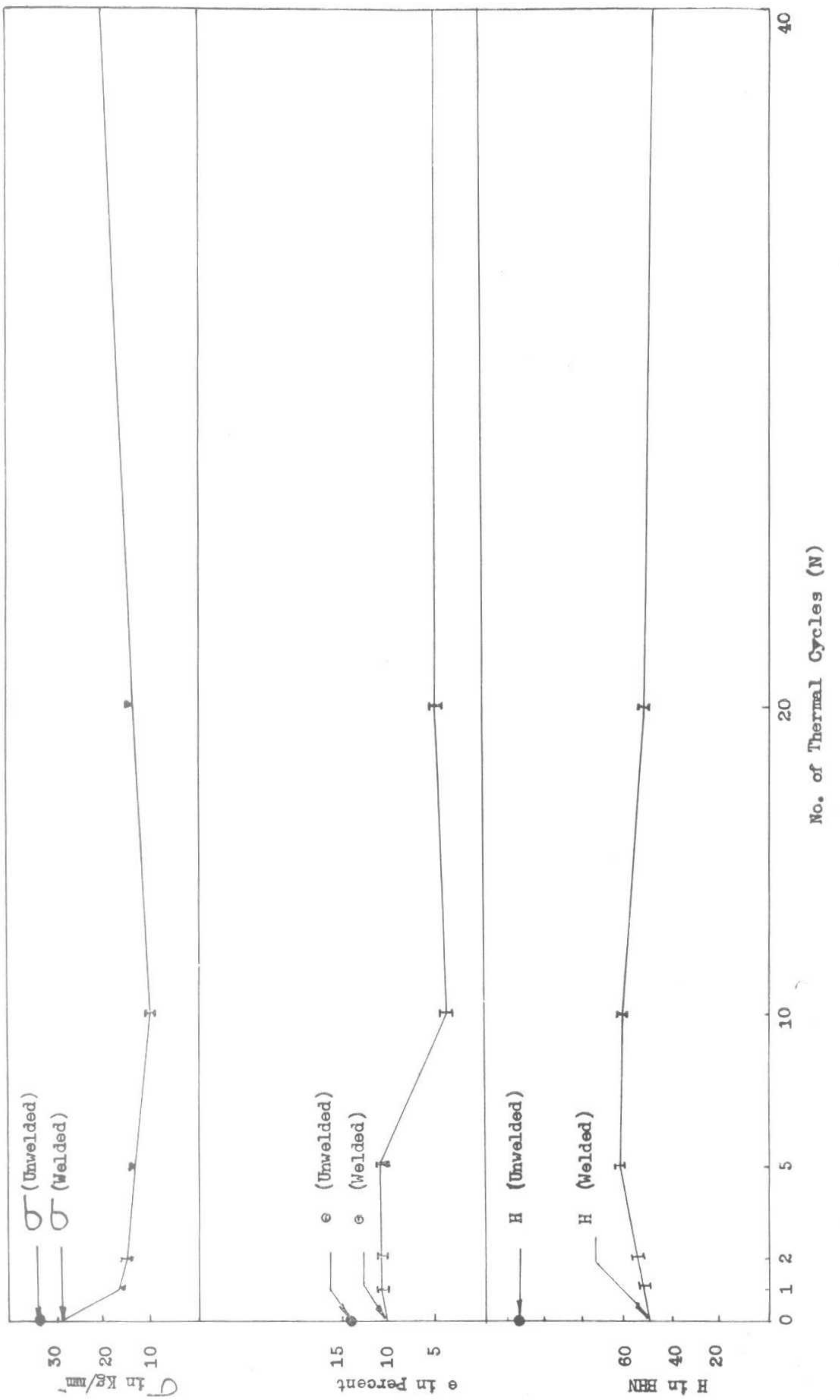
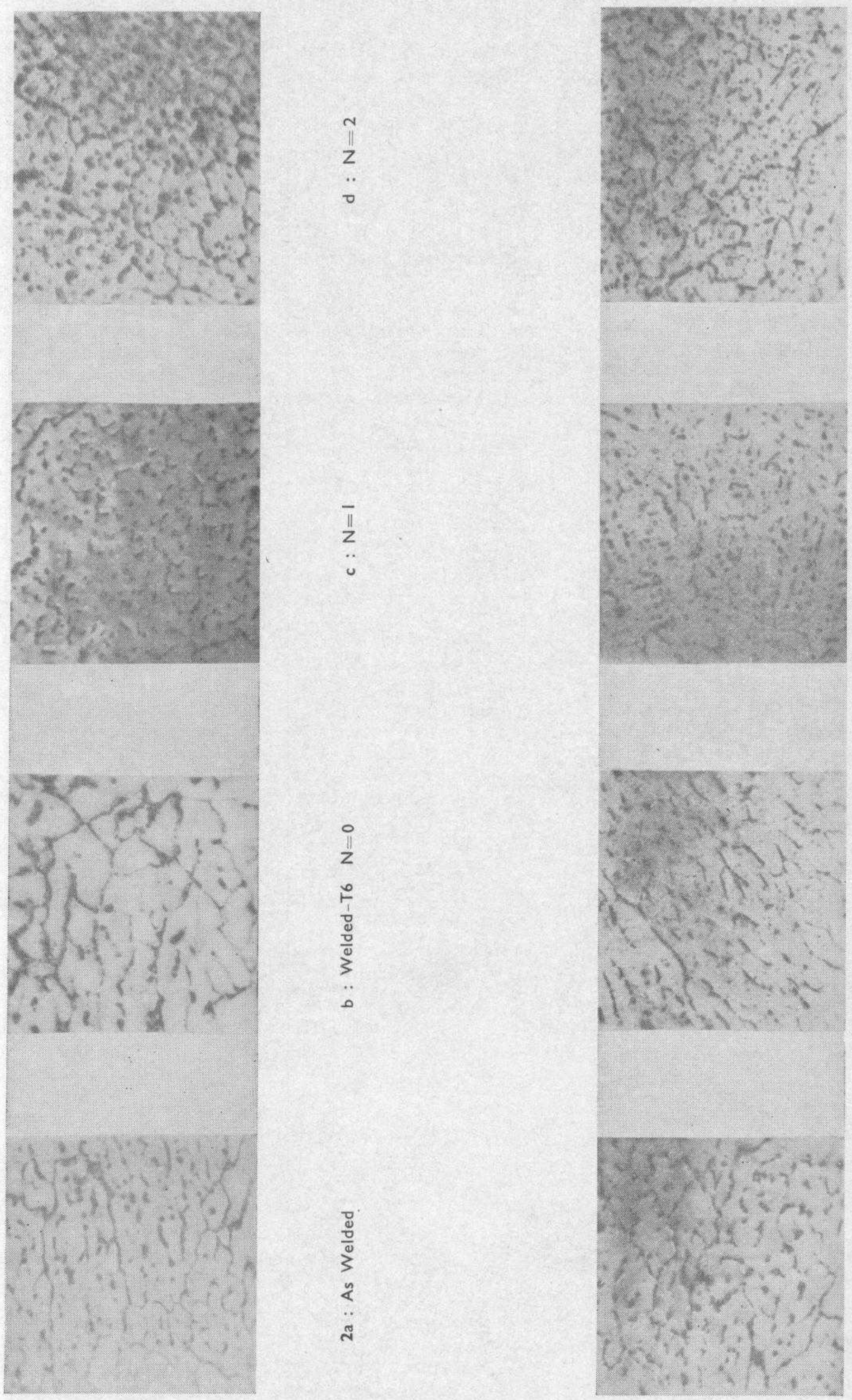


1 *Influence of thermal cycling in air between 120°C and room temperature on tensile strength (σ), elongation (e) and hardness (H) of welded 6061–T6 aluminium alloy*



2a : As Welded

b : Welded-T6 N=0

c : N=1

d : N=2

e : N=5

: N=10

g : N=20

h : N=40

×240

2 *Influence of thermal cycling on microstructures of 6061-T6 aluminium alloy weldments*

Vickers Hardness testing machine respectively. The elongation (e) values were calculated from the tensile test data.

In order to correlate the variation of the mechanical properties with the microstructure, the thermally cycled samples were electropolished on weldments using an electrolyte of the composition : perchloric acid 8 ml, methyl alcohol 175 ml, glycerin 25 ml, methyl glycol 100 ml, and photomicrographs were taken with a magnification of 240× in a Univesal 'MeF' Reichert microscope.

Results

The curves in Figure 1 reveal the variation of σ, e, and H with the number of thermal cycling (N), and it will be observed that, σ decreases to a minimum up to N = 10 rising again through N = 20 ; H reaches the maximum at N = 5 falling down through N = 20 at N = 40 to value much lower than the BHN at N =0, while e remains almost constant up to N =5, dropping down to a minimum at N=10 after which a slow rise of the elongation curve is observed. In what follows, an attempt has been made to correlate the mechanical properties of the material at various stages of thermal cycling with the microstructure.

Discussion

Due to welding by argon arc, the bulk of the alloy is molten to a superheated liquid followed by rapid cooling analogous to chill casting giving rise to the microstructure shown in Fig. 2a. Such a treatment causes fall in the properties as evidenced in Fig. 1 where the comparison between the unwelded (indicated by arrows), and welded material in T6 condition at N = 0 is presented. Further, the "as-received" sheets in T6 condition contained certain amount of the effect of the initial coldwork, plus the precipitates due to the T6 heat treatment ; however, during welding the coldwork is completely removed and only the effects of T6 treatment could be predominant resulting in the fall in the values of σ, e and H from the unwelded[3] condition to the welded one at N = 0.

By further cycling from N = 1 up to about N = 10 (Figs. 2b through 2f), in general, fragmentation of grain boundaries accompanied by spheroidal precipitation along the grain boundaries may be the cause of fall in σ, and e as well as rise in H. By subsequent thermal cycling beyond N = 10 up to N = 40, due to overageing, change in the shape of the precipitates from spheroidal to platelet structure etc., the rise in σ, and e as well as the fall in H might have taken place (Figs. 2g, and h).

Summary and conclusion

The mechanical properties of welded 6061–T6 aluminium alloy are influenced by thermal cycling markedly due to grain boundary fragmentation coupled with a complex system of precipitation phenomena. Further detailed studies are worthwhile.

Acknowledgements

The authors would like to record their deep sense of gratitude to Dr Vikram A. Sarabhai, Chairman, Atomic Energy Commission, and Dr Brahm Prakash, Director, Metallurgy Group, Bhabha Atomic Research Centre, Bombay, for their encouragement in presenting the paper at the Symposium on 'Non-ferrous Metals' Technology' to be held at Jamshedpur during December 1968. The kind co-operation of Dr T. Banerjee, Director, National Metallurgical Laboratory, Jamshedpur, as well as his staff is also gratefully acknowledged. The colleagues of Space Science and Technology Centre as well as Thumba Equatorial Rocket Launching Station, Trivandrum, are thanked for their prompt co-operation in rendering all help concerning the experimental work.

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Discussions

Mr **A. K. Bhattacharyya** (R. D. S. O., Chittaranjan) : What was the filler rod composition used for the study ?

Dr **M. K. Mukherjee** (Author) : The filler rod composition was the same as that of the parent plate mentioned in the paper and it was found from chemical analysis that there was not much variation of composition of weldments. Hence the changes in mechanical properties could be due to thermal cycling only.