NEW WELDING TECHNIQUES FOR AEROSPACE THIN-WALLED STRUCTURES ICAS-92-6.8.2

—— LSND TECHNOLOGY

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Abstract

Low Stress Non-Distortion (LSND) welding is a new technique for in- process active control of welding stress and distortion during the manufacturing of thin walled structural elements. Low stress non-distortion results are achieved by using LSND welding technique. The technique involves creating a specific uneven temperature distribution on the workpieces, restraining forces are applied to the workpieces in order to prevent the out of plane buckling which is caused by both the heating and welding operations. The stretching effect which is induced by the specific uneven temperature distribution is always following the welding heat source and controls quantitativelly the formation of incompatible plastic strains in weld zone.

Experiments show that welded using LSND welding technique can be completely distortion-free and keep their original pre-welding appearance and the level of residual stresses on the workpiece can be below a critical value, it can be ignored in engineering applications.

In practice, the LSND welding technique is suitable for ferrous as well as non-ferrous metals thickness from o.8 to 6 mm and may be applied to a variety of different welding situations. Plates and cylindrical or conical shells can be butt welded by LSND welding technique.

1. Introduction

It is a commonly accepted concept that the buckling distortions are inevitable in thin walled structures where fusion welding is applied. From the point of view of structural design integrity, rationality of manufacturing technology and in service reliability, the problems of welding residual stresses and buckling distortions in thin walled structures are the main problems which often cause variable quality of products and addtional time-consuming and costly operations to remove distortions or to relieve residual stresses after welding.

Many metheds are adopted to eliminate welding distortions and stresses in thin walled structures. The methed described in Japannese patent JP-A-6018292 is based on creating an appropriate temperature gradient on plates after welding by cooling welding zone and heating both sides ajacent to the weld; another methed using the thermal absorbing effect of volative materials described in SU-A-1066765; Japannese patent JP-A-5311138 described a methed of controlling distortion during welding of panels with reinforced ribs. These metheds above stated have limitations in applications and are not suitable for controlling welding distortions and stresses of thin walled shells in aerospace structures.

The tensile stresses induced in specimens by a preset temperature gradient as a results of cooling the weld zone and heating side zones close to the weld for controlling stresses and distortions during welding are discussed by Soviet authors in papers presented in "Automatic Welding" No. 3, 1977 and No. 5, 1979. The authors recommended an approximate calculation for thin plates but experiments were carried out only on specimens with thicknesses of 4 mm and above. No further reports are available on experiments with thicknesses less than 4 mm, nor any application of this methed in practice. It has been identified by experiments carried out at BAMTRI that this methed could not be as effective as expected for thin walled elements especialy with thicknesses less than 4 mm in which the problem of buckling distortion is significant, and it has also been proved by the results of repeated experiments that the required preset tensile stresses in the joint area of workpieces to be welded cease to exist when transient buckling distortion occurs in area with compressive stresses as a result of the superposition of the preset temperature distribution and the welding temperature distribution.

The main idea of low stress non-distortionwelding of thin walled structural elements is to create an active in-process control of welding stress and distortion during welding by a 'stretching effect ' provided by a preset temperature distribution. In this way, buckling distortion in thin walled structures can be prevented completely and welding distortion is no longer inevitable using the LSND welding technique. The conventional passive post-welding flattening procedures for correction of distortion are no longer necessary.

2. Experimental study

The experimental programme included welding of sheet specimens of both aluminium alloy and stainless steel to demonstrate the distortion-free effect by LSND welding technique in comparison with conventional welding process and residual stress measurement to provide a more clear quantitative assessment of stress level to be achieved.

In experiments aluminium alloy and stainless steel sheet materials were used. The thickness were 0.8-6 mm and dimension of the specimens were 2 pieces of 1000x 100 mm butt welded.

Tungsten inert gas arc welding without filler wire was used in all experiments.

Welding conditions were selected in accordance with material and thicknesses to provide full penetration and remained the same for both conventional welding and LSND welding.

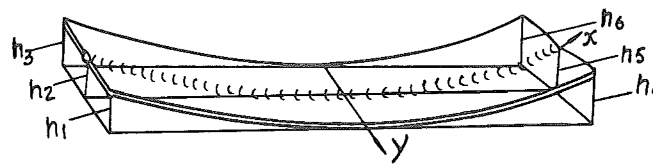
Typical buckling distortions on thin sheet specimens caused by welding are shown in Fig.1. Deflection in both horizontal and vertical position of specimens were measured on all specimens after welding. The quantitative assessments of deflections shown in Fig.1a and 1b were taken by an averaged value as follows:
in horizontal position:

$$h=(\sum_{1}^{n} h_i)/n$$

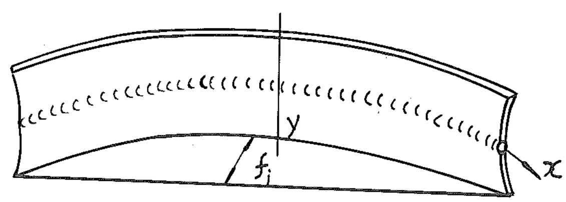
in vertical position:

$$f=(\sum_{1}^{n} f_i)/n$$

where n= number of measurments.



a. Distortion in horizontal position



b. Deflection in vertical position

Fig.1. Typical buckling distortion on thin sheet specimen caused by conventional welding.

It is well known that thin sheet specimens are the most sensitive to buckling caused by welding residual stresses above the critical level. The essential part of the research programme was to provide a quantitative assessment of the levels of residual stresses in welded specimens for comparison between conventional welding and LSND welding.

Strain gauges and mechanical extensometer were used for measuring residual stress. Measurements are taken on both top and bottom surfaces of each specimen.

3. Basic principle for execution LSND welding technique

The invention originally patented in China* is aimed at providing a methed and relevant apparatus for controlling welding stresses and distortions, executable directly in -process during welding of thin walled structural elements with thickness especially less than 4 mm in which buckling distortions are substantial for industrial application, this methed and apparatus must be simple in operation and in manipulation, economical in energy consuption and not necessitating great investment in large special purpose instalations. By means of this methed and the apparatus manufactured practical low stress and non-distortion welding results were successfully achieved.

The specific and essential feature of LSND welding is to provide the required stretching effect during welding by means of preventing the workpieces from transient out of plane buckling distortions which take place as a result of superposition of the preset heating and the welding heat source itself. The stretching effect is herein defined as the tensile stress distribution in the weld joint zone induced by a local preset heating temperature distribution as shown in Fig.2. The higher the level of tensile stress, the better the results of controlling the welding stresses and distortions. The preset tensile stresses in the weld joint zone are formed due to contraction, by cooling of the first and the third zones and expansion by heating of the second zone on both side zones adjacent to the weld. Temperature profiles are duplicated on each side. If out-of-plane buckling distortion take place during heating and welding, the stretching effect in term of σ_{max} in Fig.2 will no longer be in existence and this will have an adverse influence on the control of welding stresses and distortions.

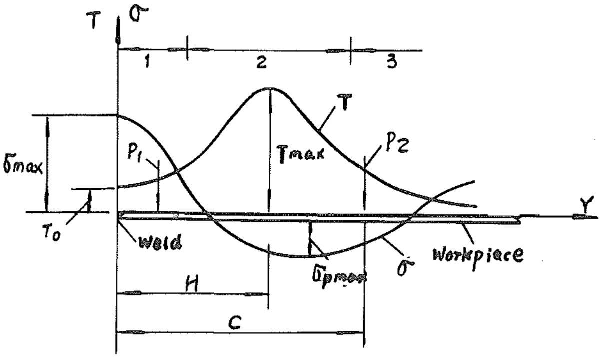


Fig.2. Scheme showing the principle of LSND welding.

In thin walled structural elements to be welded, transient buckling distortions would normally occur under compressive stresses caused by preset heating and welding. Based on the theory of plates and shells, analyses of welded structures indicate that plates with thicknesses above 4 mm are possessed of higher critical compressive stress at which buckling occurs, therefore structural elements of thicknesses above 4 mm are less sensitive to levels of compressive stresses with respect to buckling. But in the case of plates of thickness less than 4 mm, which have lower critical compressive stress at which buckling occurs, structural elements are more sensitive to changes in levels of compressive stresses during local preset heating as well as welding. Buckling distortions will take place in the workpieces while welding is superposed on the local preset heating.

In accordance with the above mentioned for LSND welding of longitudinal butt joints, the workpieces are held by restraining fixtures at both the weld zone and the third zones, by applying double flattening forces at points P1 and P2 as shown in Fig.2.

To carry the LSND welding technique into execution, the local preset temperature distributions induced by the heating are determined mainly by three parameters shown in Fig.2: T_{max}, T_o and H. The stretching effect due to σ_{max} becomes more effective as (T_{max} - T_o) increases and H decreases. It is not essential during heating and welding to keep the value of σ_{max} at a level lower than the yield stress of the material at the temperature T_{max}. According to the mechanical and thermophysical properties of the material to be welded, as well as the specific characteristics of the structure itself, these main parameters T_{max}, T_o and H are selected by use of experimental measurements in combination with theoretical analyses of the thermal elastic-plastic stress-strain cycles with references to the specific welding conditions.

Fig.3 is diagrammatic view showing example of the LSND welding methed and apparatus for longitudinal butt welding of plane elements and cylindrical shells: 1-cooling; 2-heating; 3-arc; 4.6-workpiece; 5-double finger clamping; 7- mandrel supports.

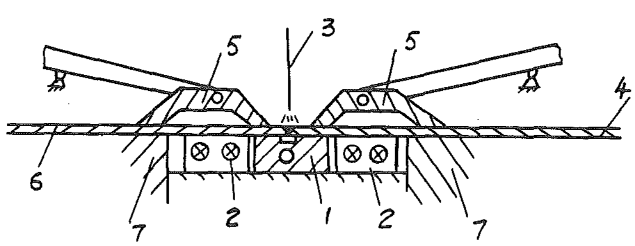


Fig.3. Diagrammatic view showing LSND welding methed and apparatus.

In this stationary welding case, the action of the restraining fixtures at both the weld zone and the third zones has the following effects:

a. The prevention of transient out of plane buckling;

b. The improvement of conduction heat sinking with the third and cool zone;

c. The increase in frictional resistance to in-plane rotating movement.

The points on each side of the weld zone at which flattening forces are to be applied are selected such that the first point is as close to the line of the weld as practicable while the second point is within the third zone but as close as practicable to the second zone. The value of the flattening forces necessary to prevent the structural elements from transient buckling are determined by the specific characteristics of the material used and the structure to be welded.

To measure the required temperature distribution, a series of thermocouples were arranged in cross sections of the specimens.

4. Experimental results on distortion control and residual stresses

Successful results on in-process welding distortion control were obtained in all cases pre-designed in the research programme. To demonstrate the effectiveness of LSND welding technique in comparison with conventional welding, preliminary experiments were carried out to show the necessity of applying the second flattening forces as the specific feature of LSND welding technique.

As demonstrated in Fig. 4, the reason why conventional welding always causes buckling of thin sheet elements is because of transient out of plane buckling which follows the welding heat source during the welding process. The transient out of plane buckling becomes even more visible in conventional jigging systems with 'one-point' clamping when local cooling and heating are applied, In the case of conventional one-point clamping by P1, transient out of plane buckling distortion always take place under compressive stresses in thin walled structural elements caused by the combined effects of the local preset heating temperature distribution and the welding temperature distribution. Once transient buckling occurs, the potential energy induced by the stretching stress distribution and accumulated in the structural elements before buckling is released and reduced to a minimum, and the value of σ_{max}(see Fig.2) re-

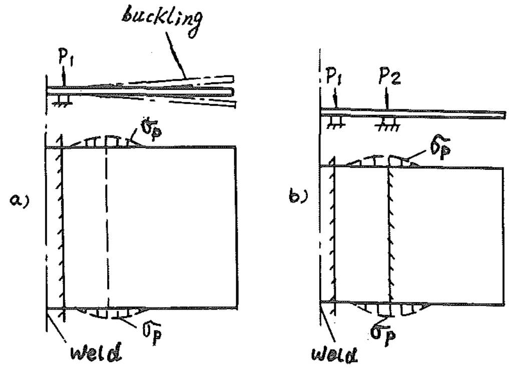


Fig.4. Transient out-of-plane buckling in'one-point' clamping system(a) and its prevention in 'two-point' clamping system (b).

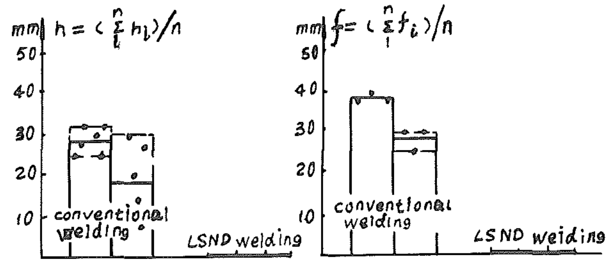
duced suddenly . Therefore, the stretching effect is no longer effective, and the low stress non-distortion welding result can not be achieved even if there is still a local preset heating temperature distribution in the workpiece to be welded. The structural elements can be kept free from any transient out of plane buckling if flattening forces P2 are additionally applied to the workpiece (see Fig.4b).

Results also show that distortion-free results cannot be obtained by welding just in a 'two-point' clamping(double-clamping) system without preset temperature distribution (without heating and cooling), because of the absence of the stretching effect as mentioned above.

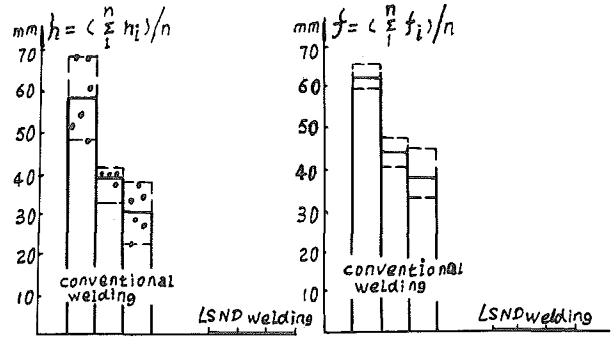
In can be seen that the stretching effect by preset heating and double clamping are the necessary and sufficient conditions respectively for LSND welding of thin materials.

Completely distortion-free results were achieved in all cases of both stainless steel and aluminium alloy using LSND welding. Fig.5 shows that a typical photopicture of welded speciments. It can be seen that the specimens welded conventionally are severaly buckled but those welded by use of LSND technique are completely distortion-free.

For quantitative assessment, these results are also shown graphically in Fig.6.



a. Stainless steel 1.6 mm



b. Aluminium alloy 1.6 mm

Fig.6. Comparison between conventional welding and LSND welding in buckling distortion.

Up to now, it is still a commonly accepted concept that buckling distortions in thin walled structures due to conventional fusion welding processes are inevitable because of the local non-uniform heating by the welding heat source which causes incompatible residual compressive plastic strains in the weld zone. As a consequence of the incompatible strains (mainly compressive plastic strains, and also phase transformation), residual stresses are formed and are balanced by compressive stresses which cause buckling distortion. Hence, the main target to be achieved by the LSND welding technique for in-process active control stress or distortion should be the prevention of the formation of plastic strains in the weld zone.

Experiments on measurements of residual incompatible compressive plastic strain ε_x^p and stress σ_x on various materials gave evidence of the scientific and technical excellence of the LSND welding technique. Fig.7a and7b show a typical compa-

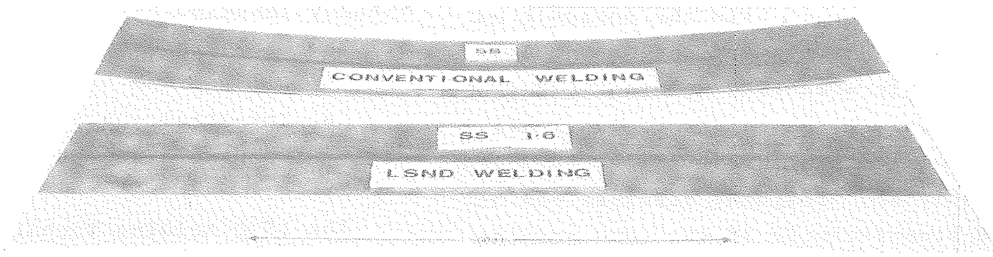


Fig5a. 1.6mm thickness stainless steel after TIG welding using conventional jigging system(severely buckled) and LSND technique(distortion free)

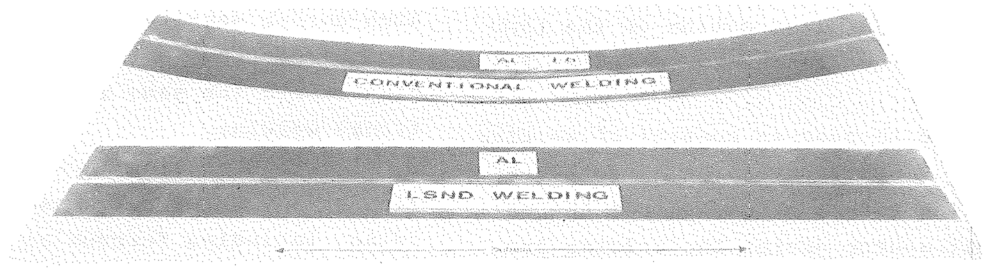


Fig5b. 1.6mm thickness aluminium sheet after TIG welding using conventional jigging system(severely buckled)and LSND technique(distortion free)

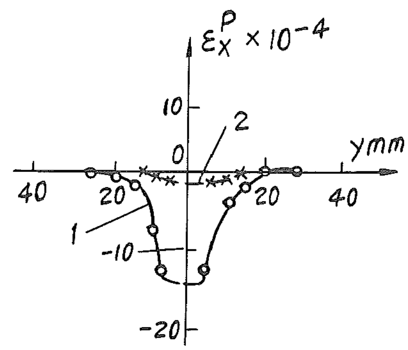
rison between conventional welding(curve 1) and LSND welding (curve 2) on LF 6 aluminium alloy specimens of 500x200x1.5 mm, It can be seen in Fig.7a that ε_x^p are at a lower level resulting in reduction of the residual peak tensile stresses σ_x by more than two thirds of the value of conventional welding (see Fig. 7b). As the compressive stresses in the specimens are also reduced correspondingly to a practically negligible level, lower than the critical level which causes buckling, a distortion-free result can be achieved.

Therefore, by introducing the new LSND welding technique, buckling in thin walled structures welded by fusion welding is no longer inevitable.

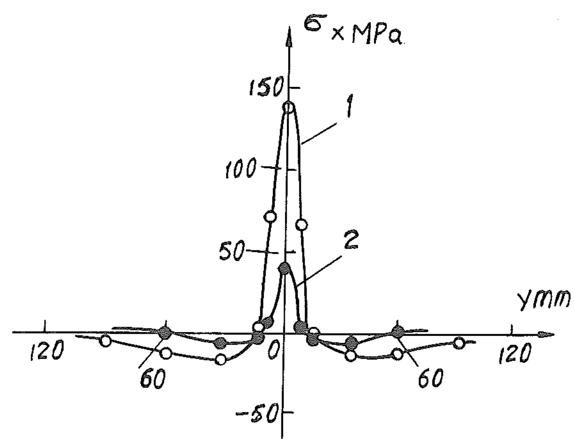
Results also show that the residual stresses were reduced by LSND welding on stainless steel specimens.

5. Discussion

Experimentsl results clearly demonstrated the successful achievement of LSND welding. The idea of 'active' in-process control of welding stresses and distortions during welding leads on a new technology in manufacturing of thin walled structural elements free from welding distortion. However, designers and manufactures who suffer from problems of welding distortions and residual stresses can now adoped a new



a. residual strains



b. residual stresses

Fig.7. Comparison between conventional welding and LSND welding in residual strains and stresses

concept, in contract with the commonly accepted one, that distortions are no longer inevitable with LSND welding technique. Buckling distortions which are substantial in thin walled structures can be prevented completedly and residual stresses can be reduced significantly if the LSND welding technique is used properly.

The main factors determining the nature and successful execution of the LSND welding technique can be summaried as follows:

(1). Active in-process control of welding stress and distortion can be executed by a stretching effect which follows the welding heat source during the welding process itself;

(2). The stretching effect in turn is provided by establushing a preset specific temperature distribution (local heating and cooling) in which required temperature gradient induces thermal tensile stresses in weld zone;

(3). The stretching effect can not be built up if welding of thin sheet element is carried out in a conventional ' one-point' clamping jig system owing to the transient out of plane buckling of workpieces which take place during conventional welding, especially if local heating is applied to both side areas adjacent to the weld.

(4). The stretching effect by specific temperature distribution can be built up if restraining fixtures (e.g. 'two-point' clamping) are applied to prevent transient out of plane buckling movement of the workpieces.

For given characteristics of materials and structure, heating to an optimised temperature distribution and maintaining it during welding can be imposed automatically through a control block stored in the control board for selecting the local preset heating temperature distributions. Therefore, by using the apparatus, all the parameters for welding and controlling procedures can be regulated properly and easily. For industrial application a stationary longitudinal seam welder for LSND welding has been manufactured.

6. Potential application of LSND welding techniques

The LSND welding technique may be carried out with many known welding heat sources, e.g. gas flames, electric arc, high energy density beams etc. The welding parameters in the case of LSND welding remain the same as used in conventional welding.

The LSND welding technique are suitable for any metal which can be fusion welding, including ferrous as well as nonferrous metals. The benefits of the technique maj be expected to be especially significant in the case of welding materials which suffer the greatest distortions, such as titanium and aluminium alloys. Post-welding distortion removal reworking operations on these materials are costly and are not always successful. The thickness of thin walled structural elements to be welded by LSND welding can be defined as mentioned above by theory of plates and shells. Significant distortion-free result can be achieved especially with elements of thickness less than 4 mm.

The LSND welding technique may be applied to a variety of different weld situations. Plates as well as cylindrical or conical shells can be butt welded by LSND welding technique. In addition, it can also be used for straight fillet and T type welds for panels with ribs.

The LSND welding technique has been used in some situations of aerospace industry.

Reference

* Guan Q. Guo D.L. et al : "Methed and apparatus for low stress and non-distortion welding of thin-walled structural elements ", Chinese Patent No.87100959, 28th Februatry 1987.