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Parametrical analysis of Friction Stir Welding of dissimilar aluminum AA7075 and AA2024 using Graph Labeling

J.Jayapriya[1], D. Muruganandam[2], K. Thirusangu[3] and Sushil lal das[4]

[1,2]*Research Scholar, Sathyabama University, Chennai-119*
[3]*Department of Mathematics, S.I.V.E.T College, Chennai-73*
[4]*Department of Mechanical Engineering, Jeppiaar Engineering College, Chennai-119*
priyanandam_1975@rediffmail.com, murudurai@gmail.com, kthirusangu@gmail.com

Abstract

In this paper the numerical data involved during the processes of welding is stored over a graph structure and its changes during compression are analyzed by using max/mini edge labeling.

Keywords: Graph, Function, Labeling, Alloy, Welding, Max/mini labeling.

AMS Subject Classification: *05C78*

Introduction

A graph labeling technique is an assignment of integers to the vertices or edges or both subject to certain conditions. Labeled graphs are becoming an increasingly useful family of Mathematical Models from a broad range of applications. The graph labeling problem that appears in graph theory has a fast development recently. This problem was first introduced by Alex Rosa in 1967. Since Rosa's article, many different types of graph labeling problems have been defined around this. This is not only due to its mathematical importance but also because of the wide range of the applications arising from this area, for instance, X-rays, crystallography, coding theory, radar, astronomy, circuit design, and design of good Radar Type Codes, Missile Guidance Codes and Convolution Codes with optimal autocorrelation properties and communication design. An enormous body of literature has grown around this subject is about 1300 papers. They gave birth to families of graphs with attractive names such as graceful, Harmonious, felicitous, elegant, cordial, magic, antimagic, bimagic and prime labeling etc. A useful survey to know about the numerous graph labeling methods is the one by Gallian (2011). All graphs considered here are finite simple, connected and undirected. Friction stir welding (FSW) is a solid state welding process for joining of alloys such as joining aluminum, magnesium and copper alloys and has been employed in several industrial application. The various parameters are such as rotational speed, longitudinal speed and axial force etc. The aim of this study is to investigate the effect of different rotational speed and tool pin profile on the weld quality of AA2024 aluminum which has gathered wide acceptance in the fabrication of light weight structures requiring a high strength-to-weight ratio. The appearance of the weld is found good and no obvious defect is found using these tools. The grain of the weld nugget is very fine and the precipitation distributes equally. Consequently, the obtained results elucidate the variation of stress as a function of strain and the effect of different rotational speed and pin profiles on yield strength and elongation.

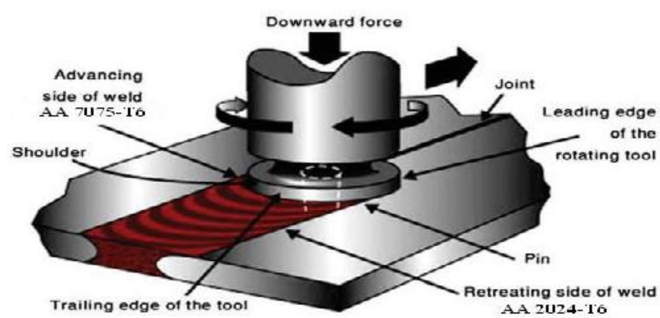

Fig 1.Showing the schematic diagram of FSW

Fig 2. AA2024-AA7075 compressive tested specimens for Taper threaded tool (a) TT1 (b) TT2 and for Straight threaded tool (c) ST1 (d) ST2

Table.1 Typical parameter combinations used for investigation

Types of Tool used	Notation used	Rotational speed (rpm)	Welding speed (mm/min)	Axial load(KN)
Taper threaded	TT1	600	30	2.5
	TT2	700	30	2.5
	TT3	800	30	2.5
	TT4	900	30	2.5
	TT5	800	20	2.5
	TT6	800	40	2.5
	TT7	800	50	2.5
	TT8	800	60	2.5
Straight threaded	ST1	600	30	2.5
	ST2	700	30	2.5
	ST3	800	30	2.5
	ST4	900	30	2.5
	ST5	700	20	2.5
	ST6	700	40	2.5
	ST7	700	50	2.5
	ST8	700	60	2.5

Table 2. Compressive properties for typical combinations used for investigation

Combinations	Tool rotation speed (rpm)	Root bend	Face bend
AA2024 – AA7075 (TT1)	600	Crack observed after 42°	No cracks observed

Main Definition

Max/ mini edge labeling: Let G (V, E) be a simple undirected graph where V = $\{x_1, x_2 \ldots x_m\}$ is a set of vertices or nodes, E = $\{e_1, e_2 \ldots e_n\}$, a set of pairs of distinct vertices, called edges or lines. Let f: V $\to$ R*, where R*= R-{0} is a set of real numbers.If the weight of each edge is defined by $e_k = \frac{\max\{f(x_i), f(x_j)\}}{\min\{f(x_i), f(x_j)\}}, 1 \le i, j \le m$, n and $i \neq j$, k = 1, 2, 3, ..., |E| is distinct then the labeling is called as Max/mini edge labeling. A graph which admits a Max/mini edge labeling is called as Max/ mini edge labeling graph.

Analyzing Welding by using Graph Labeling

Let G(V, E) represent a graph whose vertices V are V = $\{(a_{ij}); 1 \le i \le m, 1 \le j \le n\}$, m, n $\in$ N where N is a set of natural numbers and |V| = mn. (i.e. a_{ij} represent the vertices identified by i^{th} row and j^{th} column, where i = 1, 2, …, m, j = 1, 2, …, n.) which gives a bijective mapping defined as follows

Case (i): When n is even the bijection
$f : V \to R^*$ is defined as the following

$$f(a_{ij}) = \begin{cases} 2i-1 & j=1; 1 \le i \le m, \\ a_{m(j-1)} + 2i & 2 \le j \le n/2; 1 \le i \le m \\ 2i & j = n/2+1; 1 \le i \le m \\ a_{m(j-1)} + 2i & n/2+2 \le j \le n; 1 \le i \le m. \end{cases}$$

Case (ii): When n is odd the bijection
$f : V \to R^*$ is defined as the following

$$f(a_{ij}) = \begin{cases} 2i-1 & j=1; 1 \le i \le m \\ a_{m(j-1)} + 2i & 2 \le j \le \lfloor n/2 \rfloor; 1 \le i \le m \\ 2i & j = \lfloor n/2 \rfloor + 1; 1 \le i \le m \\ a_{m(j-1)} + 2i & \lfloor n/2 \rfloor + 2 \le j \le n; 1 \le i \le m. \end{cases}$$

G(V, E) is a graph obtained by merging the Dissimilar Alloys AA2024 and AA7074. Let each edge E = $\{a_{ij}\ a_{i(j+1)}$: i = 1, 2, …, m, j =1, 2, .., n–1 and $a_{ij}\ a_{(i+1)j}$: i = 1, 2, …, m–1, j = 1, 2, .., n}. Let R_i represent the rows where i = 1, 2, 3, …, m.

Due to compression the changes in each of (a_{ij}) give rise to new graph $G_c(V_c, E_c)$ which induces a mapping $f^* : V^* \to R^*$ (i.e. b_{ij} represent the vertices identified by i^{th} row and j^{th} column, where i = 1, 2, …, m_g , j = 1, 2, …, n_s), where

$V_c = \{b_{ij}; 1 \le i \le m_g; 1 \le j \le n_s\}$,

$E_c = \{b_{ij}\ b_{i(j+1)}: 1 \le i \le m_g;\ 1 \le j \le (n-1)_s\} \cup \{ b_{ij}\ b_{(i+1)j} : 1 \le i \le (m-1)_g;\ j = 1, 2, ..., n_s\}$

Algorithm:

Before compression test:

Input: The number of rows m and columns n of the graph G.

```
begin
V = {(aij); 1 ≤ i ≤ m, 1 ≤ j ≤ n}
for i = 1 to m; n ≡ 0 (mod 2)
{if (j = 1)
    {f (aij) = 2i–1}
    for (j = 2 to n/2)
    {f (aij) = am(j-1) +2i}
        if (j = n/2+1)
        {f (aij)= 2i}
        for (j = n/2+2 to n)
        {f (aij) = am(j-1) +2i}
    }
for i = 1 to m; n ≡ 1 (mod 2)
{if (j = 1)
```

{f(a_{ij})= 2i-1 }

for (j = 2 to ⌊ n/2 ⌋)

{f (a_{ij})= $a_{m(j-1)}$ +2i}

if (j = ⌊ n/2 ⌋+1)

{f (a_{ij})= 2i}

for (j = ⌊ n/2 ⌋+2 to n)

{f (a_{ij}) = $a_{m(j-1)}$ +2i}

}.

E= {a_{ij} $a_{i(j+1)}$: i = 1, 2, ..., m, j = 1, 2, .., n−1and a_{ij} $a_{(i+1)j}$: i = 1, 2, ..., m−1, j = 1, 2, .., n}.

Output: The Graph G.

After compression test:

Input:

E_c= {$b_{ij}b_{(j+1)}$: 1 ≤ i ≤ m_g; 1 ≤ j ≤ $(n-1)_s$ Ụ{ b_{ij} $b_{(i+1)j}$: 1 ≤ i ≤ $(m-1)_g$; j = 1, 2, .., n_s}

for (i= 1 to m_g, j = 1 to n_s)

{

{for (h = 1 ≤ n_s)

e_h = (max (b_{ij}, $b_{i(j+1)}$) / (min (b_{ij}, $b_{i(j+1)}$) }

{for (h = 1 ≤ n_s)

e_v = (max (b_{ij}, ($b_{(i+1)j}$) / (min (b_{ij}, $b_{(i+1)j}$)}

}

Output: The Graph G_c.

Result: If each of the elements of e_h and e_v is found to be distinct then the welding is stronger else not stronger.

Illustration

Initial State

Let G = (V, E) where V = {a_{ij}; 1 ≤ i ≤ 7, 1 ≤ j ≤ 4} i.e. a_{ij} represent the vertices identified by i^{th} row and j^{th} column, and E = {a_{ij} $a_{i(j+1)}$: i = 1, 2, 3, 4, 5, 6, 7, j = 1, 2, 3 and a_{ij} a_{i+1j} : i = 1, 2, 3, 4, 5, 6, j =1, 2, 3, 4}, where k = 1, 2, ..., 24.i.e.

E = {$a_{11}a_{12}$, $a_{12}a_{13}$, $a_{13}a_{14}$, $a_{11}a_{21}$, $a_{12}a_{22}$, $a_{13}a_{23}$, $a_{14}a_{24}$, $a_{21}a_{22}$, $a_{22}a_{23}$, $a_{23}a_{24}$, $a_{31}a_{32}$, $a_{32}a_{33}$, $a_{33}a_{34}$, $a_{21}a_{31}$, $a_{22}a_{32}$, $a_{23}a_{33}$, $a_{24}a_{34}$, $a_{41}a_{42}$, $a_{42}a_{43}$, $a_{43}a_{44}$, $a_{31}a_{41}$, $a_{32}a_{42}$, $a_{33}a_{43}$, $a_{34}a_{44}$, $a_{41}a_{51}$, $a_{42}a_{52}$, $a_{43}a_{53}$, $a_{44}a_{54}$, $a_{51}a_{52}$, $a_{52}a_{53}$, $a_{53}a_{54}$, $a_{51}a_{61}$, $a_{52}a_{62}$, $a_{53}a_{63}$, $a_{54}a_{64}$, $a_{61}a_{62}$, $a_{62}a_{63}$, $a_{63}a_{64}$, $a_{61}a_{71}$, $a_{62}a_{72}$, $a_{63}a_{73}$, $a_{64}a_{74}$, $a_{71}a_{72}$, $a_{72}a_{73}$, $a_{73}a_{74}$}. Let f : V → R^*, where R^* is a set of real numbers

$$f(a_{ij}) = \begin{cases} 2i-1 & \text{if } j=1, i=1,2,3,4,5,6,7 \\ a_{71}+2i & \text{if } j=2, i=1,2,3,4,5,6,7 \\ 2i & \text{if } j=3, i=1,2,3,4,5,6,7 \\ a_{73}+2i & \text{if } j=4, i=1,2,3,4,5,6,7. \end{cases}$$

Let R_i represent the rows where i = 1, 2, 3, 4, 5, 6, 7 whose entries are elements of (a_{ij}); 1 ≤ i ≤ 7, 1 ≤ j ≤ 4

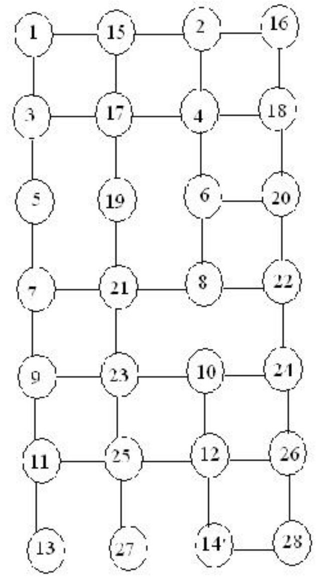

Fig 3. Welded work piece of AA7075 and AA2024 Graph-G

Final State

When a COMPRESSIVE load is applied then we have only four rows namely R^1_1 , R^1_2 , R^1_3 and R^1_4 whose entries are as follows

1. R^1_1= (R_1 +R_2)/2
2. R^1_2= (R_2 + R_3)/2
3. R^1_3= (R_5 +R_6)/2
4 .R^1_4= R_5 + R_6- R_7

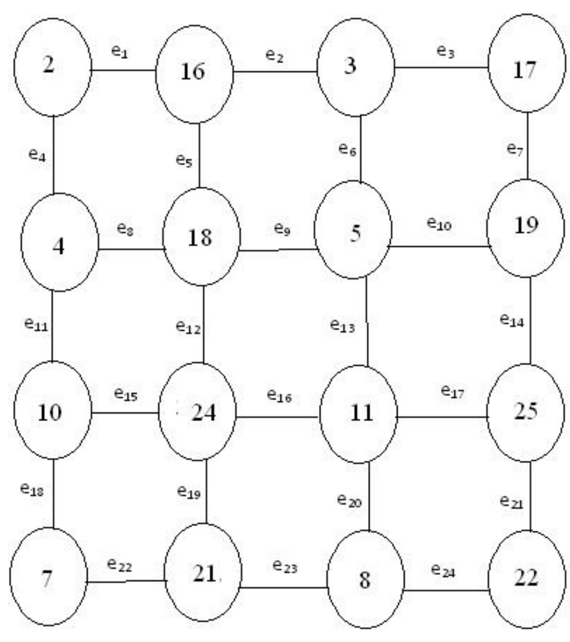

*Fig 4. After Compression test Graph-G**

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Result

The max/min edge Labeling (shown in Table 3) is computed for each edge after compression test by using $e_k = \{(\max(b_{ij}, b_{i(j+1)}) / (\min(b_{ij}, b_{i(j+1)})\} \cup \{(\max(b_{ij}, (b_{(i+1)j}) / (\min(b_{ij}, b_{(i+1)j})\}$
$1 \le i \le 4$, $1 \le j \le 4$.
is found to be distinct real numbers therefore the Welding is stronger.

Table 3. Computation of Max/mini of edges

Edges (e_k)'s	Computation of Max/mini of edges
e_1	8
e_2	5.333333
e_3	5.666667
e_4	2
e_5	1.125
e_6	1.66666667
e_7	1.123
e_8	4.5
e_9	3.6
e_{10}	3.8
e_{11}	2.5
e_{12}	1.333333
e_{13}	2.2
e_{14}	1.375789
e_{15}	2.4
e_{16}	2.181818
e_{17}	2.72727
e_{18}	1.4287143
e_{19}	1.14285714
e_{20}	1.375
e_{21}	1.4666667
e_{22}	3
e_{23}	2.625
e_{24}	2.75

Conclusion

In a welded plate a compressive test being conducted by which it is proven that by using Max/mini edge labeling welding is stronger.

References

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