KBS-Weld - Project

PREDICTION OF IMPERFECTIONS AND MECHANICAL PROPERTIES IN THE GMAW PROCESS

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1. Introduction

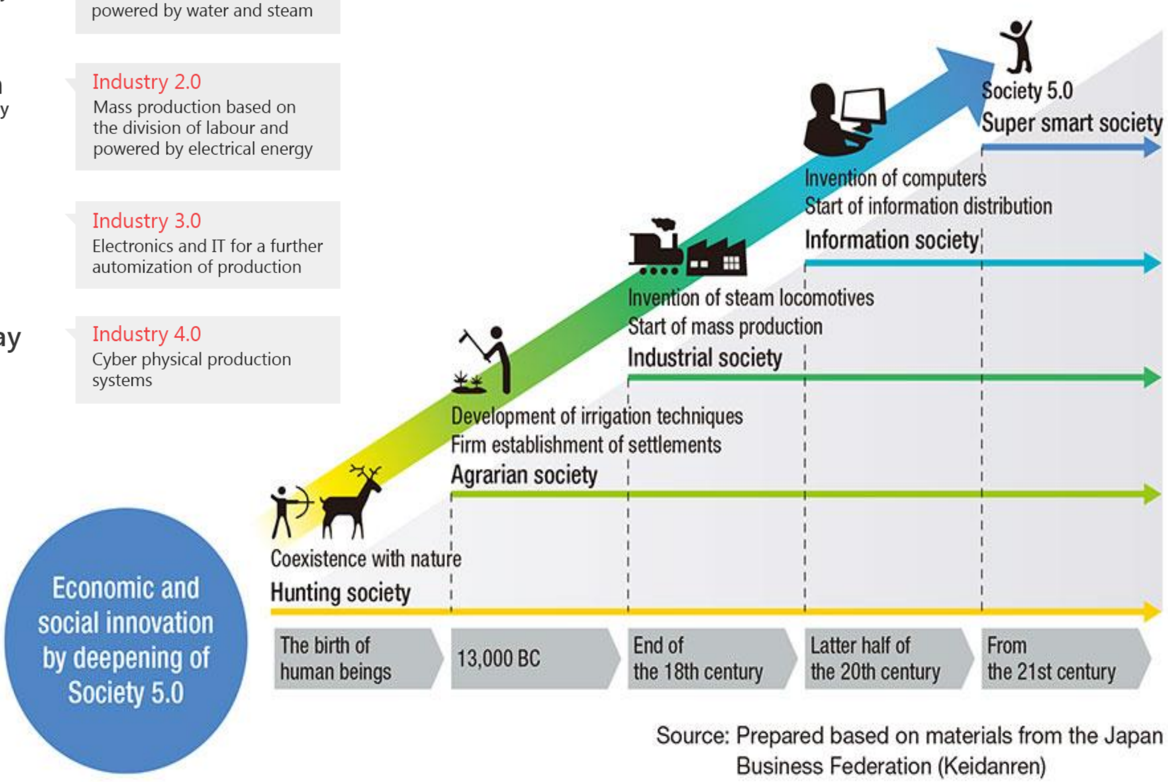
Welding is an essential manufacturing process performed in almost every major industry.

The weld quality and integrity are critical to safety for an extensive range of products and structures.

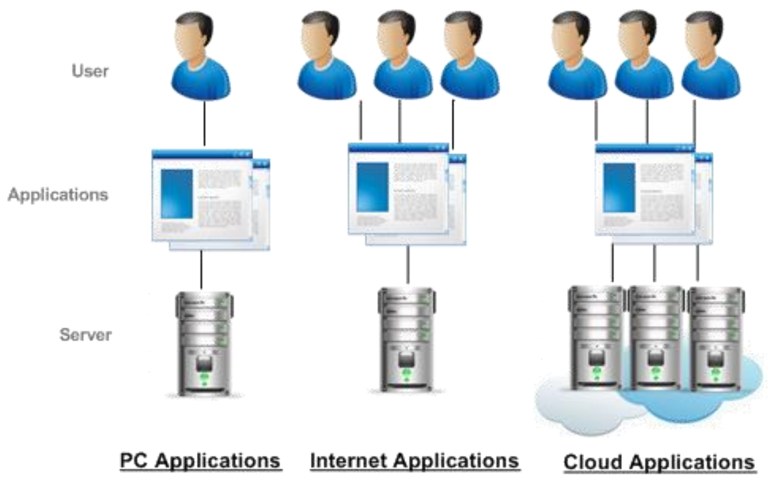
The past, present and future of Industrial (r)evolution

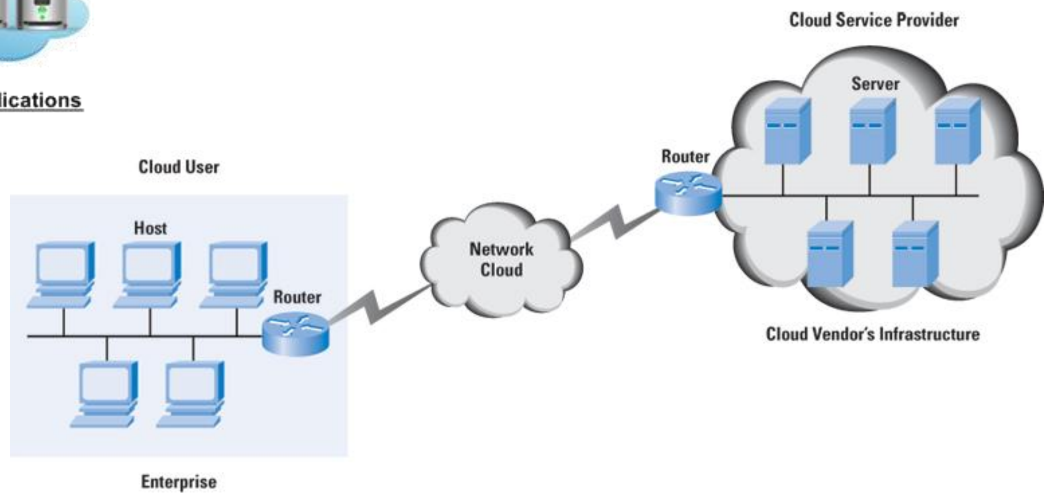
HISTORY OF INDUSTRIAL REVOLUTION

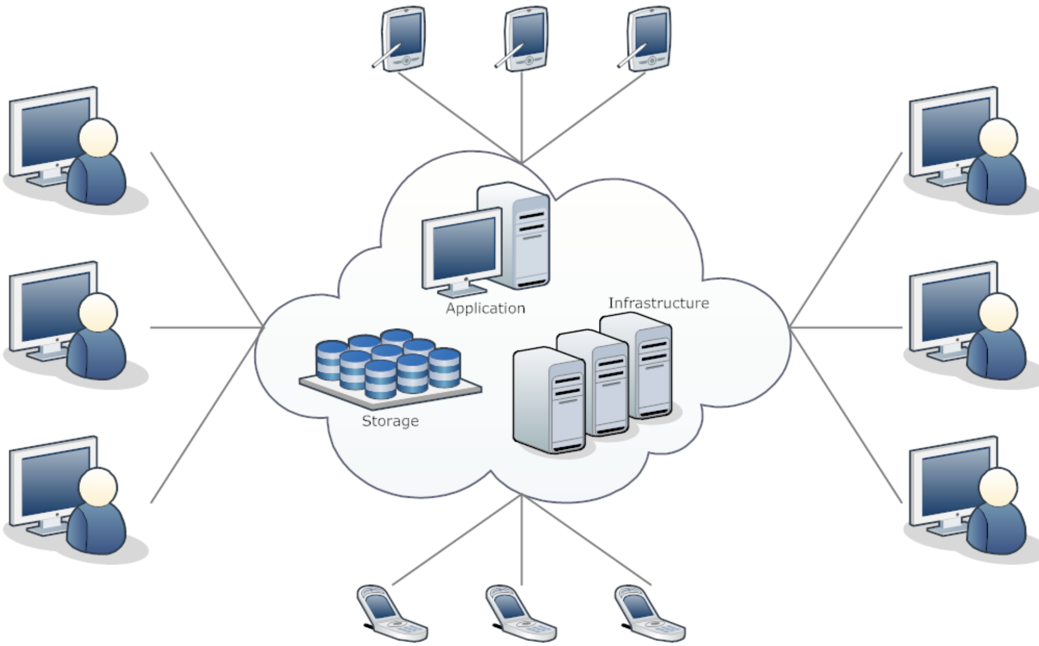
- **18th Century** — Industry 1.0: Mechanical production powered by water and steam
- **20th Century** — Industry 2.0: Mass production based on the division of labour and powered by electrical energy
- **70s** — Industry 3.0: Electronics and IT for a further automization of production
- **Today** — Industry 4.0: Cyber physical production systems



Source: Prepared based on materials from the Japan Business Federation (Keidanren)


User
Applications
Server
PC Applications
Internet Applications
Cloud Applications


Cloud Service Provider
Server
Router
Cloud Vendor's Infrastructure
Network Cloud
Cloud User
Host
Router
Enterprise



A welding system for a connected world.

Weld data captured.
Internet enabled.
Cloud aware.
Remotely managed.
Automatically updated.

1. Introduction

GMAW is one of the most ***commonly used arc welding process*** and is continuously improved by selecting the best combination of welding materials, welding technologies and welding parameters to produce a welded structure with the required properties.

In GMAW, as in any welding process, the ***welding parameters*** play an important role in product quality as it affects the mechanical properties, structural characteristics and geometry of welded joints.

1. Introduction

Selecting the optimal welding parameters to meet the required specifications ***is complicated*** as the welding quality can be affected by several variables such as the chemical composition of the base materials and heat treatment, wire and protective gas used.

Among the various widely used methods, in the current studies the ***factorial experimental*** design method was used to identify the significant process parameters and to obtain ***correlations*** between the welding parameters and output indicators related to the quality of joints, as this method is useful for modelling and analyzing of issues involving multiple parameters.


YASKAWA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2. Experimental work

2.1 Material and methods

For the experimental work, S235JR+AR structural steel plates of 2 mm, 4 mm and 8 mm thickness, according to SR EN 10025-2 were used as base material. The chemical composition of the base material is presented in table 1 and the main mechanical characteristics are presented in the table 2.

Table 1 Chemical composition of the base material, S235JR+AR structural steel

C [%]	Mn [%]	P [%]	S [%]	N [%]	Cu [%]
0,19	1,50	0,045	0,045	0,014	0,60

Table 2 Mechanical composition of the base material, S235JR+AR structural steel

Yield strength $Rp_{0,2}$ [N/mm²]	Tensile strength R_m [N/mm²]	Elongation at break A_5 [%]	Impact energy $KV_{(+20°C)}$ [J]
235	360 - 510	26	27

2. Experimental work

2.1 Material and methods

To prepare the weld, 1.0 mm diameter 3Si1 welding wire (according to SR EN ISO 14341, commercial naming BÖHLER SG2), was used.
The chemical composition of the welding wire is presented in table 3 and the associated main mechanical characteristics are presented in table 4.

Table 3 Chemical composition of the welding wire, 3Si1

C [%]	Si [%]	Mn [%]	P [%]	S [%]	Ni [%]	Cr [%]	Mo [%]	V [%]	Cu [%]	Al [%]	Ti + Zr [%]
0.06 - 0.14	1.00 - 1.30	1.30 - 1.60	0,025	0,025	0,15	0,15	0,15	0,03	0,35	0,02	0,15

Table 4 Mechanical characteristics of the welding wire, 3Si1

Yield strength $Rp_{0,2}$ [N/mm²]	Tensile strength R_m [N/mm²]	Elongation at break A_5[%]	Impact energy $KV_{(+20°C)}$ [J]
420	500 - 640	20	27

2. Experimental work

2.1 Material and methods

M2.1 protection gas, (according to SR EN ISO 14175, commercial naming CORGON18) was used in the welding process. The main characteristics are presented in table 5.

Table 5 Characteristics of the welding gas, M2.1

Name	CO_2 [%]	Ar [%]	Volume (L)	Pressure (bar)	Content weight (kg)
M2.1 CORGON 18	15 - 25	Rest	15	200	3.88

GMAW process was used to obtain butt welded and fillet welded samples of sheets.

To avoid human error robot system (consisting of robotic arm and integrated welding source) was used to implement the experimental welding program.

2. Experimental work

2.1 Material and methods

To predict the imperfections and mechanical properties in GMAW process, factorial experiments were designed for each base material thickness, taking into account the main process parameters:

- welding current I_a[A]
- welding voltage U_a[V]
- travel speed v[cm/min]
- electrode's free length, l[mm].

Thus, the factorial experiments envisaged the study of four influence factors on two levels and included three replicas at the central point, according to table 6.

2. Experimental work

Table 6 Factorial model of welding variants

Test no.	Welding current I_a [A]	Welding voltage U_a [V]	Welding speed v [cm/min]	Free length l [mm]
1	-1	1	-1	1
2	-1	-1	-1	1
3	-1	1	-1	-1
4	1	-1	1	1
5	-1	-1	1	-1
6	1	1	-1	-1
7	1	-1	-1	1
8	1	-1	1	-1
9	1	1	1	1
10	-1	1	1	1
11	-1	-1	1	1
12	1	1	1	-1
13	1	1	-1	1
14	1	-1	-1	-1
15	-1	-1	-1	-1
16	-1	1	1	-1
17	0	0	0	0
18	0	0	0	0
19	0	0	0	0

where: “1” represented the upper value, “0” represented the center point value and “-1” represented the lower value of the studied process parameters.

2. Experimental work

The upper, center point and lower value of the parameters used in the factorial experiments, depending of the thickness of the plates and type of the welded joints. For butt welded plates, these parameters are presented in table 7 to 9.

Table 7 Welding parameters – butt welded plates of 2 mm thickness

Value	I_a [A]	U_a [V]	v [cm/min]	l [mm]
Upper	140	20	75	12
Center point	125	19	65	10
Lower	110	18	55	8

Table 8 Welding parameters – butt welded plates of 4 mm thickness

Value	I_a [A]	U_a [V]	v [cm/min]	l [mm]
Upper	155	22,5	30	12
Center point	135	21	25	10
Lower	115	19,5	20	8

Table 9 Welding parameters – butt welded plates of 8 mm thickness

Value	I_a [A]	U_a [V]	v [cm/min]	l [mm]
Upper	275	29	70	12
Center point	250	27	60	10
Lower	225	25	50	8

2. Experimental work

For fillet welded plates, these parameters are presented in table 10 to 12.

Table 10 Welding parameters – fillet welded plates of 2 mm thickness

Value	I_a [A]	U_a [V]	v [cm/min]	l [mm]
Upper	170	21	57	12
Center point	155	19	52	10
Lower	140	17	47	8

Table 11 Welding parameters – fillet welded plates of 4 mm thickness

Value	I_a [A]	U_a [V]	v [cm/min]	l [mm]
Upper	220	26	54	12
Center point	200	25	47	10
Lower	180	24	40	8

Table 12 Welding parameters – fillet welded plates of 8 mm thickness

Value	I_a [A]	U_a [V]	v [cm/min]	l [mm]
Upper	248	28.6	38.5	12
Center point	225	26.0	35.0	10
Lower	202	23.4	31.5	8

2. Experimental work

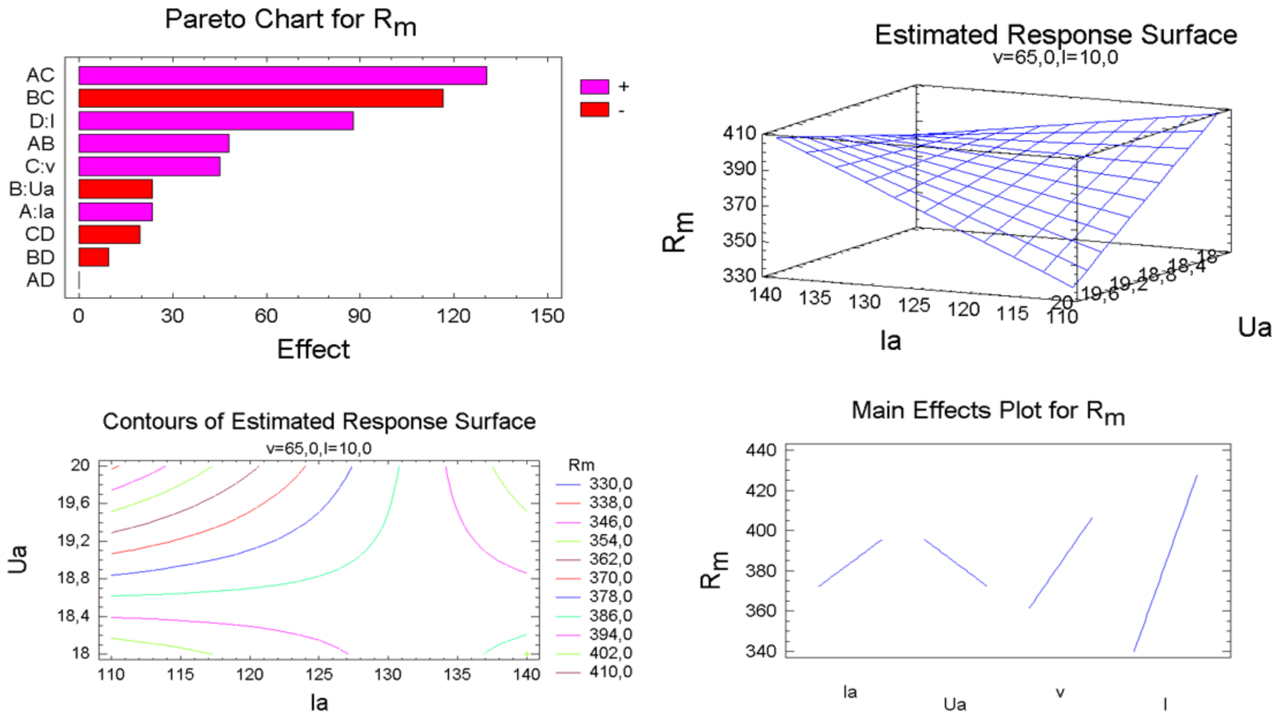
2.2 Experimental testing program

To evaluate the quality of the welded joints, a testing program was designed and implemented, consisting of:

- Non-destructive tests: MT, PT using x-ray, UT (complementary);
- Mechanical tests (tensile tests, bending tests, fracture tests);
- Hardness testes (HV) and macroscopic analysis.

3. Results and discussion

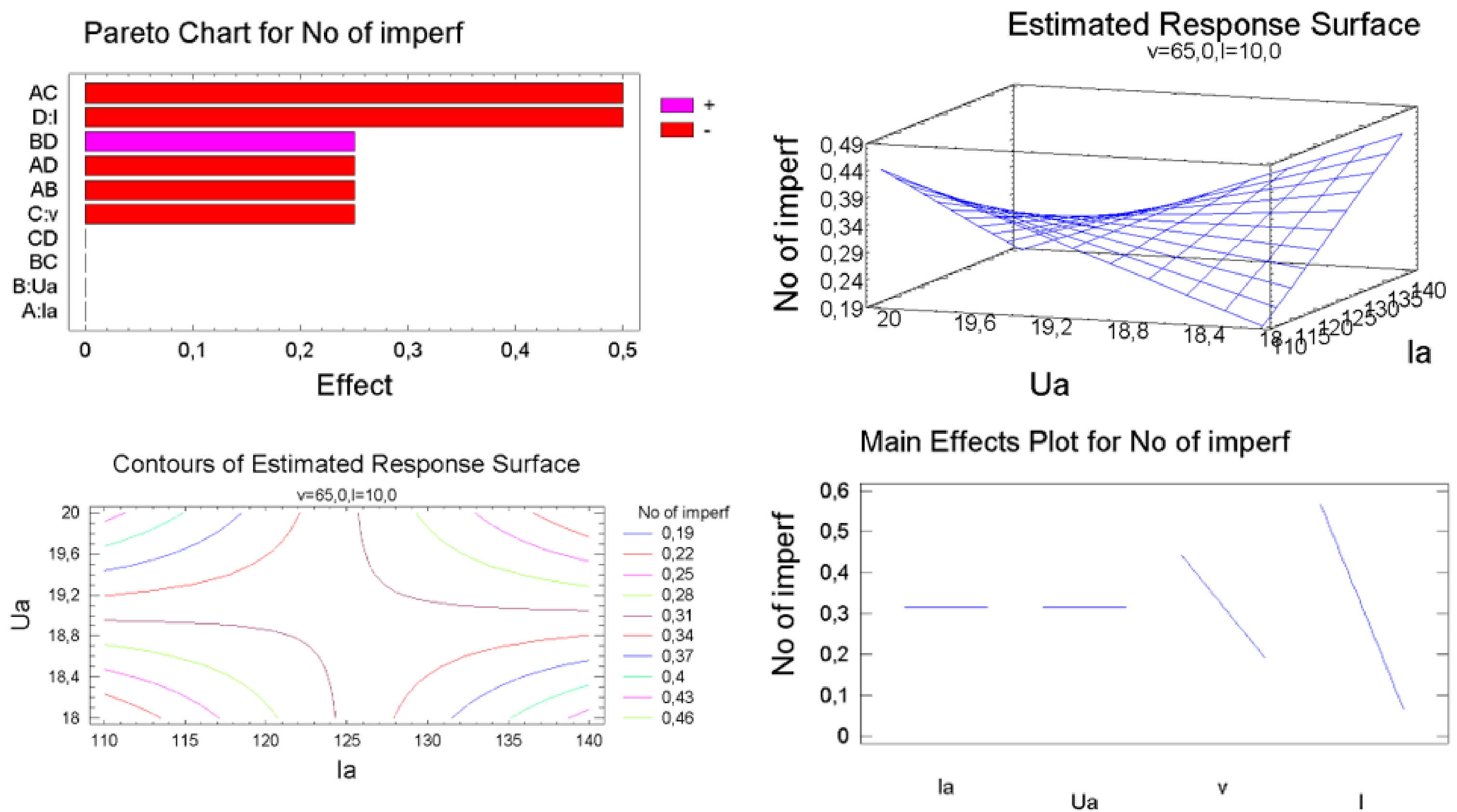
To evaluate the quality of the welded joints and the correlations between the welding parameters and the mechanical characteristics of the welded joints, specialized software for regression analysis was used.



$$R_m = -496{,}23 - 57{,}81 \cdot I_a + 191{,}12 \cdot U_a + 63{,}4 \cdot v + 99{,}3 \cdot I + 1{,}6 \cdot I_a \cdot U_a + 0{,}43 \cdot I_a \cdot v + 0{,}0021 \cdot I_a \cdot I - -5{,}82 \cdot U_a \cdot v - 2{,}41 \cdot U_a \cdot I - 0{,}49 \cdot v \cdot I$$

Figure 1 The correlations between the parameters of the welding process and the tensile strength (butt-welded plates of 2 mm thick)

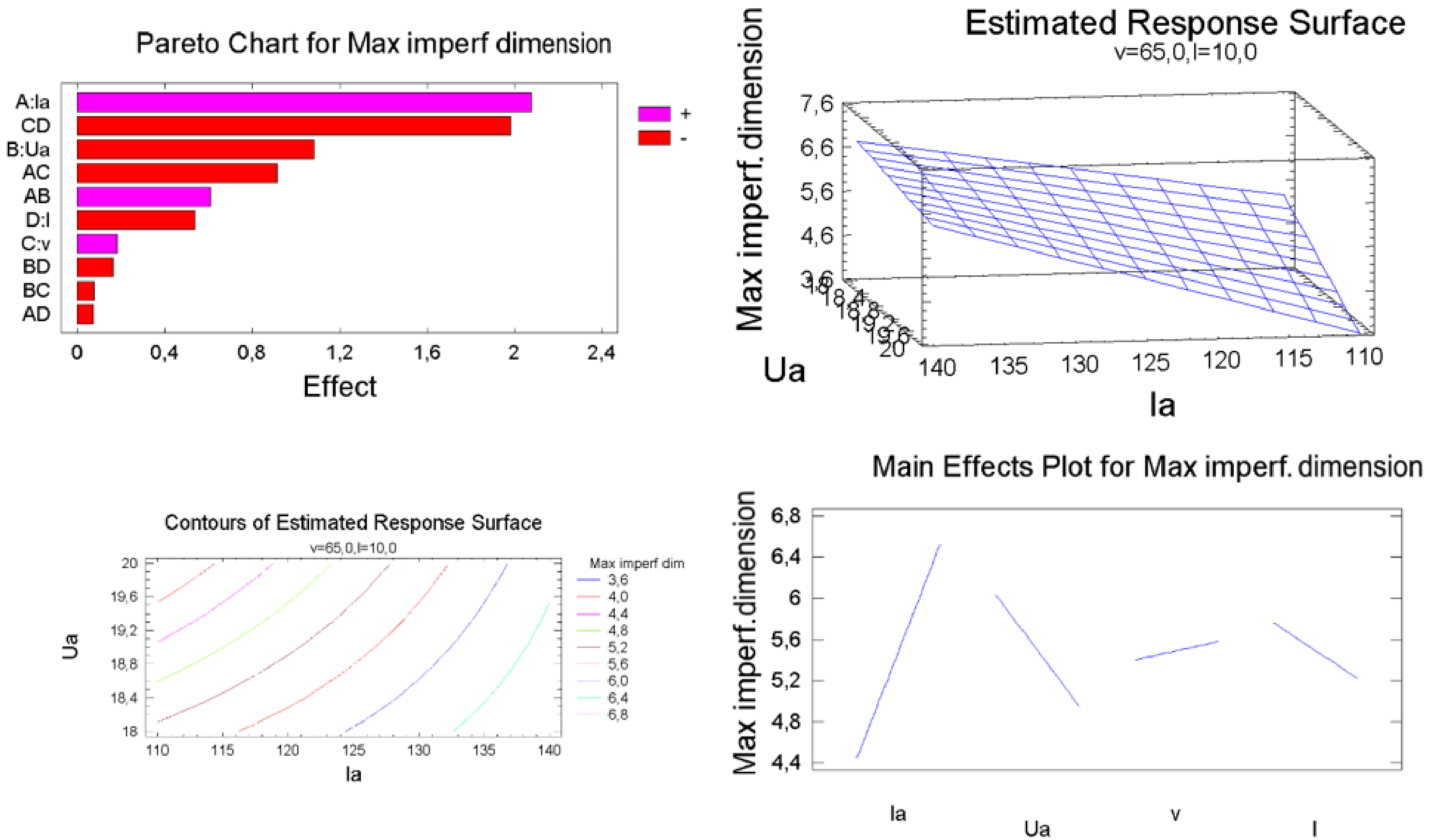
3. Results and discussion



The number of imperfections $= -24{,}29 + 0{,}31 \cdot I_a + 0{,}42 \cdot U_a + 0{,}19 \cdot v - 0{,}79 \cdot l - 0{,}0083 \cdot I_a \cdot U_a - 0{,}0016 \cdot I_a \cdot v - 0{,}0042 \cdot I_a \cdot l + 0{,}0625 \cdot U_a \cdot l$

Figure 2 The correlations between the parameters of the welding process and the number of imperfections (butt-welded plates of 2 mm thick)

3. Results and discussion



The maximum dimension of imperfection = $-14{,}9 - 0{,}106 \cdot I_a - 2{,}42 \cdot U_a + {+0{,}96} \cdot v + 4{,}02 \cdot l + {+0{,}0203} \cdot I_a \cdot U_a - 0{,}00305 \cdot I_a \cdot v - 0{,}00125 \cdot I_a \cdot l - 0{,}0039 \cdot U_a \cdot v - 0{,}041 \cdot U_a \cdot l - 0{,}05 \cdot v \cdot l$

Figure 3 The correlations between the parameters of the welding process and the maximum size of imperfections (butt-welded plates of 2 mm thick)

3. Results and discussion

In a similar way were found correlations for butt welded joints of 4 mm:

R_m = 1168,4 + 4,3·I_a - 7,5·U_a + 10,2·v - 255,3·l -0,134·I_a·U_a + 0,0418·I_a·v - 0,0611·I_a·l - -2,203·U_a·v + +8,95·U_a·l + 2,93·v·l

No. of imperfection= 6, - 0,057·I_a + 0,13·U_a - 0,13·v + +0,07·l + +0,0006·I_a·U_a - 0,0001·I_a·v +0,003·I_a·l + +0,002·U_a·v - 0,036·U_a·l + 0,012·v·l

Max. dimension of imperfection = 149,5 - 1,44·I_a + 3,38·U_a- 3,17·v + 1,82·l + +0,014·I_a·U_a - 0,002·I_a·v+ + 0,074·I_a·l + 0,056·U_a·v - 0,9·U_a·l + 0,3·v·l

Correlations for butt welded joints of 8 mm:

R_m = 371,6 + 2,94·Ia + 3,09527·Ua - 11,1·v - 4,93·l -0,083·Ia·Ua + 0,019·Ia·v - 0,164·Ia·l + 0,1·Ua·v+ 0,94·Ua·l + +0,37·v·l

No. of imperfection=-4,1 + 0,07·Ia - 0,0053·Ua -0,035·v - 0,565·l -0,0015·Ia·Ua - 0,00034·Ia·v -0,0008·Ia·l + +0,003·Ua·v + 0,018·Ua·l + 0,004·v·l

Max. dimension of imperfection=-103,1 + 1,76·Ia - 0,13·Ua -0,9·v - 14,23·l - 0,037·Ia·Ua - 0,0084·Ia·v - -0,021·Ia·l + 0,064·Ua·v + 0,47·Ua·l + 0,106·v·l

3. Results and discussion

The analysis of the obtained results, shows that the tensile strength of the welded joints increased with the increase of the electrode wire feed rate (which lead to an increase in welding current) and decreased with the increase of the welding voltage.

When the welding voltage increase, the width of the weld seam increase, and thus linear energy is distributed over a larger surface. Under these conditions, in conjunction with the other welding parameters, the linear energy may be insufficient to produce a suitable weld with a required tensile strength.

The joint tensile strength increases as the welding speed increases. This could be explained as follows: increasing in welding current leads in increasing of the deposition rate, and thus, a higher welding speed is required to obtain a proper weld.

In case of butt-welding thin plates, for the welding parameters range selected, the number of imperfections in the welded joint increase with decreasing in welding speed and with decreasing of free length (nozzle-workpiece distance).

The maximum size of detected defects increases with increasing of the welding current as well as in case of welding voltage decreases.

4. Conclusions

A factorial experiment was performed on butt welded plates and fillet welded plates of structural steel using the GMAW process. The study demonstrated that using experiments prediction of imperfections and mechanical properties in the GMAW process could be done.

The process parameters that had the greatest impact on the tensile strength of the welded joint were the welding current, the welding voltage, the welding speed and the free length.

Based on the results obtained, regression models for different thicknesses of base materials were developed. Determined regression models can be used to estimate the number and the maximal dimension of imperfections and to select parameters of the GMAW process, to obtain required tensile strength of the weld, which is exploited under different loading condition.

Obtained models could be used for structural steels of group 1, according to ISO/TR 15608:2017, with specified minimum yield strength of $R_{eH} \leq 275$ N/mm^2 .

Thank you for your attention !

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