COST OF WELDING AND COST OF WELDED STRUCTURES

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Contents

Summary

When we consider the interaction of design and technology, we should not forget the cost of the structure as the third leg of the system. These three together help us to find the best solution. These cost calculations are founded on material costs and those fabrication costs, which have direct effect on the sizes, dimensions or shape of the structure. Other costs, like amortization, investment, transportation, maintenance are not considered here. Sometimes we can predict the cost of design and inspection, but usually they are proportional to the weight of the structure. Cost and production time data come form different companies from all over the world. When we compare the same design at different countries, we should consider the differences between labor costs. It has the most impact on the structure, if the technology is the same. The cost function includes the cost of material, assembly, welding as well as surface preparation, painting and cutting, edge grinding, forming the shell and is formulated according to the fabrication sequence. The numerical examples show the differences of cost distribution at welded box beam, welded stiffened plate, and at stiffened circular cylindrical shells.

1. Introduction

The great development of fabrication technology and the new effective welding methods enable designers to construct a wide variety of load-carrying structures for each industrial application. They can compose structures from rolled, cold-formed, welded profiles, plates and shells. Since there are many possibilities to construct safe structures which fulfill the requirements on stress, fatigue, deformation, fabrication limitations, designers should find a realistic aspect to select the most suitable version.

Since the welding is an expensive manufacturing method, for welded structures this aspect is the economy, minimization of mass and cost. Therefore, an optimum design system is developed, which can fulfill all the main requirements: safety, fitness for fabrication and economy.

This system needs to analyze the production cost and formulate cost functions to be minimized in the optimization process.

The selecting aspect is the minimum cost and the best version can be determined by cost comparison. Since for the realistic comparison each candidate version should be optimized, effective optimization techniques should be used. This optimum design system is the best tool for development of economic and competitive structural types. The main parts of this system are the design and fabrication constraints, cost functions and mathematical optimization methods. Thus, the cost calculation plays an important role in the design of welded structures.

The cost of a structure is the sum of the material, fabrication, transportation, erection, maintenance and recycling costs. Fabrication cost elements are the welding-, cutting-, preparation-, assembly-, tacking-, cleaning-, painting costs, etc. It is impossible to obtain cost factors, which are valid all over the world, because there are great differences among the cost factors in different countries. There are also differences among factories in the same country due to the technological level they represent and apply. If times are chosen as the basic data of fabrication phases, this problem can be handled. The fabrication time depends on the technological level of the country and the manufacturer, but it is much closer to the real process concerned. For a given technology, fabrication times are nearly the same at all plants and the deviation is not very large. After computing the necessary time for each fabrication phase, it can be multiplied by a specific cost factor, which represents the level of development.

This chapter intends to show how to calculate fabrication costs, especially welding costs using different welding technologies. No consideration is given to cost parts which have no direct effect on the sizes of the structures to be optimized, like the amortization, transportation, erection, maintenance and recycling costs, or the variation of currency exchange rates, etc.

2. Cost Elements

Material cost

The material cost can be calculated as

$$K_m = k_m \rho V, \quad (1)$$

where K_m [in $ or in any other currency] is the material cost, k_m [$/kg] is the corresponding material cost factor, ρ [kg/mm^3] is material density, V [mm^3] is the volume of the structure. The range of k_m is between 0.5 – 1 [$/kg] according to the producers' pricelists. The material cost factor for hot-formed rectangular hollow section

(RHS) and square hollow section (SHS), according to the Price List of the British Steel Tubes and Pipes is $k_{\mathrm{m}} = 1.0$ \$/kg.

Fabrication cost

The fabrication cost can be expressed as

$$K_{\mathrm{f}} = k_{\mathrm{f}} \sum_i T_i \, , \tag{2}$$

where K_{f} [\$] is the fabrication cost, k_{f} [\$/min] is the corresponding fabrication cost factor, T_i [min] are production times. It is assumed that the value of k_{f} is constant for a given manufacturer. If not, it is possible to apply different fabrication cost factors simultaneously in Eq. (2).

Fabrication times for welding

The most important times related to welding are as follows: preparation, assembly, tacking, time of welding, changing the electrode, deslagging and chipping.

Calculation of the times of preparation, assembly and tacking

The times of preparation, assembly and tacking can be calculated with an approximation formula as follows:

$$T_1 = C_1 \delta \sqrt{\kappa \rho V} \, , \tag{3}$$

where C_1 is a parameter depending on the welding technology (usually equal to 1), δ_{dw} is a difficulty factor, κ is the number of structural elements to be assembled. Formula (3) can be approximately derived from Lihtarnikov.

The difficulty factor expresses the complexity of the assembly of the structure. Difficulty factor values depend on the kind of structure (planar, spatial), the kind of members (flat, tubular). The range of values proposed is between 1 and 4.

Calculation of real welding time

The welding technologies applied are given in Table 1. Real welding time can be calculated on the following way

$$T_2 = \sum_i C_{2i} a_{\mathrm{w}i}^n L_{\mathrm{w}i} \, , \tag{4}$$

where $a_{\mathrm{w}i}$ is weld size, $L_{\mathrm{w}i}$ is weld length, C_{2i} and n are constants for different welding technologies. C_2 contains not only the differences between welding technologies but the time differences between positional (vertical, overhead) and normal welding as well (see Tables 3-9).

Calculation of additional fabrication actions time

There are some additional fabrication actions to be considered such as changing the electrode, deslagging and chipping. The time of these is as follows

$$T_3 = \sum_i C_{3i} a_{wi}^n L_{wi} . \qquad (5)$$

Formulae (3, 4, 5) were proposed by Pahl & Beelich.

Ott & Hubka proposed that $C_3 = (0.2 - 0.4) C_2$ on average $C_3 = 0.3 C_2$. Thus, the modified formula for

$T_{w2} + T_{w3}$ neglecting $\sqrt{\Theta_d}$, is

$$T_{w2} + T_{w3} = 1.3 \sum C_{2i} a_{wi}^2 L_{wi} . \qquad (6)$$

In the negligence of $\sqrt{\Theta_{dw}}$ it is assumed that the difficulty factor should be considered only for T_{w1}.

The software COSTCOMP was developed by the Netherlands Institute of Welding. It gives welding times and costs for different welding technologies on the basis of theoretical and experimental investigations. Considering the times given by companies all over the world and the times calculated by COSTCOMP here Eq. (3) is used for T_{w1} and the other times are calculated with a generalized formula, where the power of a_w is n, which is some cases equal to 2, or close to it.

$$T_{w2} + T_{w3} = 1.3 \sum C_{2i} a_{wi}^n L_{wi} . \qquad (7)$$

The different welding technologies are shown in Table 1. The weld types are given in Tables 2a and 2b.

SMAW	Shielded Metal Arc Welding
SMAW HR	Shielded Metal Arc Welding High Recovery
GMAW-C	Gas Metal Arc Welding with CO_2
GMAW-M	Gas Metal Arc Welding with Mixed Gas
FCAW	Flux Cored Arc Welding
FCAW-MC	Metal Cored Arc Welding
SSFCAW (ISW)	Self Shielded Flux Cored Arc Welding
SAW	Submerged Arc Welding
GTAW	Gas Tungsten Arc Welding

Table 1. Welding technologies applied

Using COSTCOMP the welding times T_{w2} (min) were calculated versus weld size a_w (mm) for fillet welds (Table 3), for $1/2V$ and V butt welds (Table 4), for K and X butt welds (Table 5), for T butt welds (Table 6), for U and double U butt welds (Table 7), in downhand position. The values of power n in Eq. (7) come from curve fitting calculations.

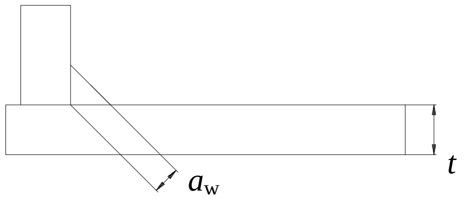
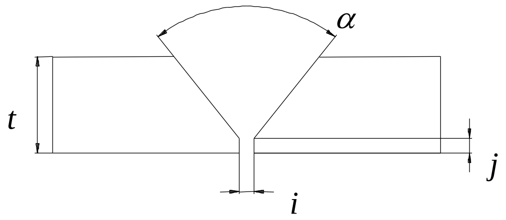
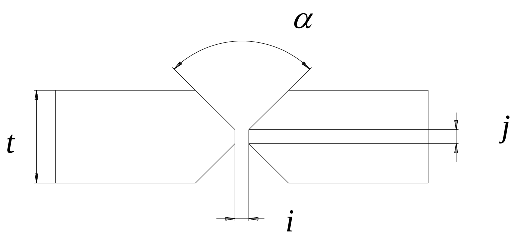
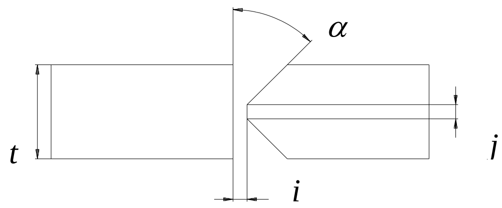
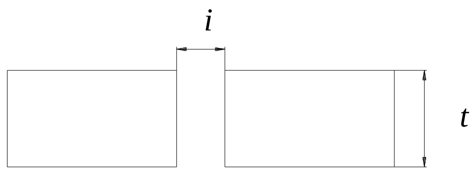
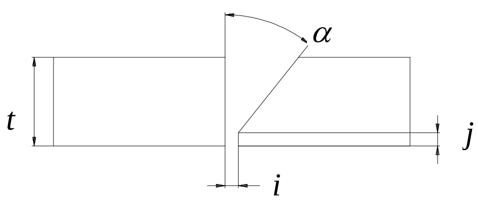
	**1. Fillet weld** t=0-15 mm a_w = 0.7 t_{min}
	**2. V butt-weld** t=4-15 mm α=40-90° i=1-2 mm j=0-2 mm

Table 2a. Different weld types, for double-sided butt welds $a_w = t$, for butt welds welded only on one side $a_w = 0.7t$.

	**3. X butt-weld** t = 10-40 mm α = 40-60° i = 2-3 mm j = 2-3 mm
	**4. K butt-weld** t = 10-40 mm α = 40-60° i = 0-3 mm j = 2-3 mm
	**5. T butt-weld** t = 2-8 mm i = t/2
	**6. 1/2 V butt-weld** t = 4-15 mm α = 40-60° i = 0-2 mm j = 0-2 mm

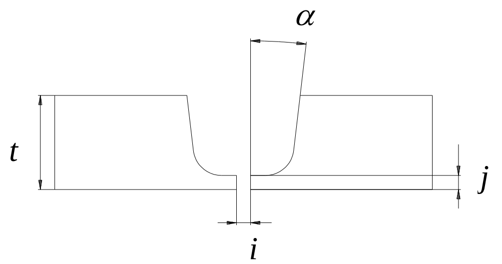
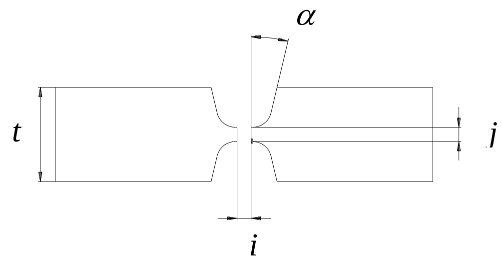
	**7. U butt-weld** t = 20-40 mm α = 10-20° i = 2-3 mm j = 2-3 mm
	**8. Double U butt-weld** t = 20-40 mm α = 10-20° i = 2-3 mm j = 2-3 mm

Table 2b. Different weld types, for double-sided butt welds $a_{\mathrm{w}} = t$, for butt welds welded only on one side $a_{\mathrm{w}} = 0.7t$.

The welding times $T_{\mathrm{w}2}$ (min/mm) versus weld size a_{w} (mm) for longitudinal fillet welds (Table 8) for longitudinal V butt welds (Table 9) in positional welding, which means not downhand, but vertical or overhead positions.

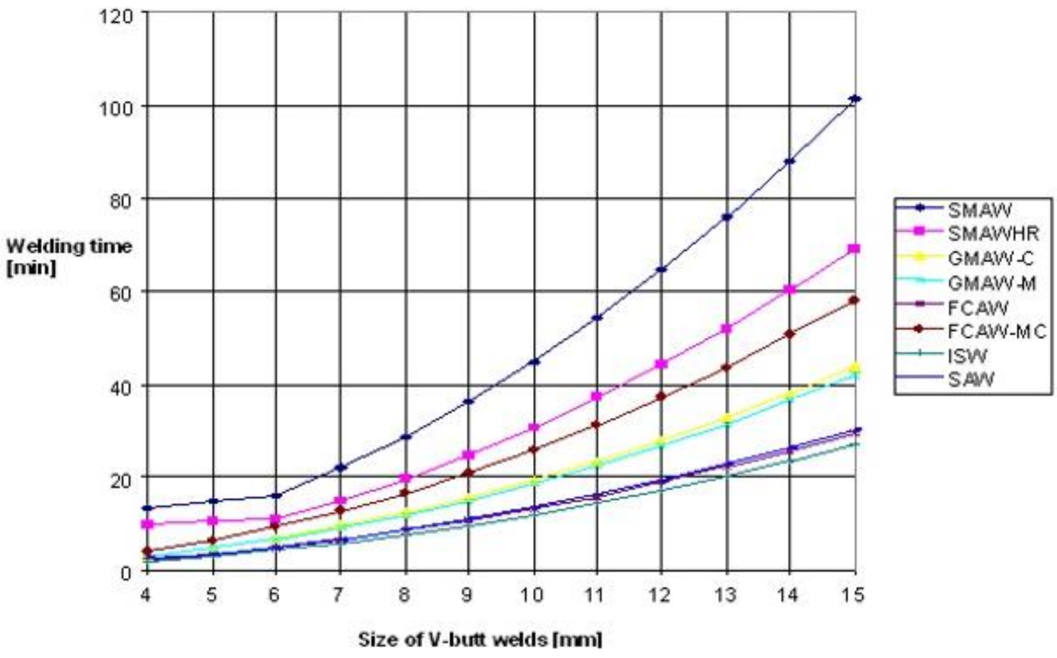


Figure 1. Welding times $T_{\mathrm{w}2}$ (min/mm) versus weld size a_{w} (mm) for longitudinal V butt welds downhand position

Figure 1 shows the welding times for longitudinal V butt welds in decreasing order SMAW, SMAW-HR, GMAW-C, GMAW-M, FCAW, FCAW-MC, ISW and SAW.

The highest and the lowest welding times being for SMAW and SAW respectively. The order is the same for different weld types (Tables 3 – 9).

Table 3 shows the calculated equations after curve fitting for longitudinal fillet welds using Eq. (7) type functions for the approximation.

Welding technology	a_w [mm]	$10^3 T_2 = 10^3 C_2 a_w^n$
SMAW	0-15	$0.7889 a_w^2$
SMAW HR	0-15	$0.5390 a_w^2$
GMAW-C	0-15	$0.3394 a_w^2$
GMAW-M	0-15	$0.3258 a_w^2$
FCAW	0-15	$0.2302 a_w^2$
FCAW-MC	0-15	$0.4520 a_w^2$
SSFCAW (ISW)	0-15	$0.2090 a_w^2$
SAW	0-15	$0.2349 a_w^2$

Table 3. Welding times T_{w2} (min/mm) versus weld size a_w (mm) for longitudinal fillet welds, downhand position

			1/2 V butt welds		V butt welds	
Welding technology	a_w [mm]		$10^3 T_2 = 10^3 C_2 a_w^n$		$10^3 T_2 = 10^3 C_2 a_w^n$	
SMAW	4-6	6-15	$3.13 a_w$	$0.5214 a_w^2$	$2.7 a_w$	$0.45 a_w^2$
SMAW HR	4-6	6-15	$2.14 a_w$	$0.3567 a_w^2$	$1.8462 a_w$	$0.3077 a_w^2$
GMAW-C	4-15		$0.2245 a_w^2$		$0.1939 a_w^2$	
GMAW-M	4-15		$0.2157 a_w^2$		$0.1861 a_w^2$	
FCAW	4-15		$0.1520 a_w^2$		$0.1311 a_w^2$	
FCAW-MC	4-15		$0.2993 a_w^2$		$0.2582 a_w^2$	
SSFCAW (ISW)	4-15		$0.1384 a_w^2$		$0.1194 a_w^2$	
SAW	4-15		$0.1559 a_w^2$		$0.1346 a_w^2$	

Table 4. Welding times T_{w2} (min/mm) versus weld size a_w (mm) for longitudinal 1/2V and V butt welds downhand position

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Biographical Sketch

Dr József Farkas is a professor emeritus of metal structures at the University of Miskolc, Hungary. He graduated in 1950 at the Faculty of Civil Engineering of the Technical University of Budapest. He has been an assistant professor of the University of Miskolc since 1950, an associate professor since 1966, a university professor since 1975. His scientific degrees are candidate of technical science 1966, doctor of technical science 1978. His research field is the optimum design of metal structures, residual welding stresses and distortions, tubular structures, stiffened plates, vibration damping of sandwich structures. He has written expert opinions for many industrial problems, especially on storage tanks, cranes, welded press frames and other metal structures. He is the author of a university textbook about metal structures, a book in English “Optimum Design of Metal Structures” (Ellis Horwood, Chichester 1984), the first author of three books in English “Analysis and Optimum Design of Metal Structures” (Balkema, Rotterdam-Brookfield 1997), “Economic Design of Metal Structures” (Millpress, Rotterdam 2003), Design and optimization of metal structures (Horwwod Publishing, Chichester, UK, 2008) and about 280 scientific articles in journals and conference proceedings. He was a Hungarian delegate of the International Institute of Welding (IIW) in years 1986-2007, member of the International Society for Structural and Multidisciplinary Optimization (ISSMO) and honorary member of the Hungarian Scientific Society of Mechanical Engineers (GTE). He is doctor honoris causa of the University of Miskolc.