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COMPARISON OF RESISTANCE LIMITS OF A WELDED JOINT OBTAINED IN TENSILE TESTS WITH CALCULATED VALUES FROM THE LITERATURE

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Abstract. Widely used in industrial environments the welding is a very old process that has been optimized over the years. Due to its ease of operation, relatively low cost and high productivity, the GMAW process is one of the most widely used types of welding. As in most industrial processes, welding also requires the correct dimensioning and control of mechanical properties. The aim of the present work is to develop an electronic calculation tool for the sizing of a weld bead obtained by GMAW process, where the user can enter with stress values and the dimensions of the weld bead and the program returns whether the welded joint will withstand the stress. To cover a larger number of people who could use this tool, the software chosen for the spreadsheet was "Microsoft Excel". This spreadsheet was developed based on the equations found in the "Mechanical Engineering Design" literature by J. E. Shigley, et. al. To validate the results of the spreadsheet, test specimens were prepared, which were submitted to tensile tests. It was concluded that the spreadsheet calculates the welded joint subjected to tensile stresses correctly, but with a margin of safety, since, through the experimental tests, it was found that the joint still supports a load larger than calculated by the spreadsheet.

Keywords: GMAW welding, weld bead sizing, spreadsheet.

1. INTRODUCTION

Widely used in industrial environments, the welding consist in a metallurgical process that aims in a permanent union of two components. This process is based in melting of the materials involved to formation of welded joint.

After concluded the welding process, gets a component constituted by two fundamentals parts, the weld zone (WZ) and thermal affected zone (TAZ). The WZ is formed by a melted part of base metal and filler metal. The TAZ is a material part that was not melted, but had their properties modified by the heat generated in the process. These characteristics are substantially proportional to base metal and the process selected. Because the crystalline structure of the TAZ is ruder than the rest of material, this critical area must be considered in the efforts and resistances calculation (Marques *et. al.*, 2011).

There are various methods to sizing a weld bead calculation, due to type of effort involved, so that the results indicate an evaluation as to the mechanical resistance, or a safety coefficient, who make possible an indicative of maximum tension supported by the weld bead until the rupture. However, when sizing a weld bead, is required the evaluation, not only of the resistance of this bead, but also of base materials to be united. Shigley *et. al.* (2009) shows the equations required to this sizing, as also the factors who influencing in the resistance of a welding joint.

The accomplishment of the calculations to evaluate the resistance, in their context, must consider the conditions that will be used in the welding process. This work aims the development of a spreadsheet that realize the sizing of a weld bead obtained by MIG process in which the input data are the dimensions of the weld bead and the force exerted on it.

2. EXPERIMENTAL AND COMPUTATIONAL PROCEDURE

The software Microsoft Excel is used for the development of the spreadsheet, once a large number of people could use due the ease and nearness with the software. In this spreadsheet, was provided the equations and tables withdrawals from "Mechanical Engineering Design" literature by Joseph E. Shigley, Charles R. Mischke and Richard G. Budynas (Shigley *et. al.*, 2009), as shown in the section 2.1. Section 2.2 refers to the methodology used in the tensile tests.

2.1 Spreadsheet development

The spreadsheet was designed to analyze a top joint, made of carbon steel and exposed to the pure tensile stress, as shown in Fig. 1.

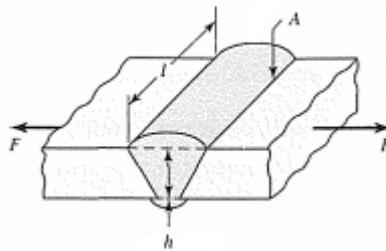


Figure 1. Top joint exposed to tensile stress

Where "l" refers to the length of the weld bead, "h" to the high of the weld throat and "F" to the applied tensile force. Having the values of these dimensions, the mean normal stress (σ) can be calculated by Eq. (1).

$$\sigma = \frac{F}{h.l} \tag{1}$$

In order to determine the force "F" that can be applied, it is necessary to observe the values of tensile strength and yield strength, both for welding and for base metals. The values of tensile strength and yield strength as well as Brinell hardness values for the base metals can be observed in Tab. 1.

Table 1 - Deterministic ASTM Minimum Tensile and Yield Strengths for Some Hot-Rolled (HR) and Cold-Drawn (CD) Steels.

SAE and/or AISI No.	Proces- sing	Tensile Strength, MPa (kpsi)	Yield Strength, MPa (kpsi)	Elongation in 2 in, %	Reduction in Area, %	Brinell Hardness
1006	HR	300 (43)	170 (24)	30	55	86
	CD	330 (48)	280 (41)	20	45	95
1010	HR	320 (47)	180 (26)	28	50	95
	CD	370 (53)	300 (44)	20	40	105
1015	HR	340 (50)	190 (27.5)	28	50	101
	CD	390 (56)	320 (47)	18	40	111
1018	HR	400 (58)	220 (32)	25	50	116
	CD	440 (64)	370 (54)	15	40	126
1020	HR	380 (55)	210 (30)	25	50	111
	CD	470 (68)	390 (57)	15	40	131
1030	HR	470 (68)	260 (37.5)	20	42	137
	CD	520 (76)	440 (64)	12	35	149
1035	HR	500 (72)	270 (39.5)	18	40	143
	CD	550 (80)	460 (67)	12	35	163
1040	HR	520 (76)	290 (42)	18	40	149
	CD	590 (85)	490 (71)	12	35	170
1045	HR	570 (82)	310 (45)	16	40	163
	CD	630 (91)	530 (77)	12	35	179
1050	HR	620 (90)	340 (49.5)	15	35	179
	CD	690 (100)	580 (84)	10	30	197
1060	HR	680 (98)	370 (54)	12	30	201
1080	HR	770 (112)	420 (61.5)	10	25	229
1095	HR	830 (120)	460 (66)	10	25	248

The values of tensile strength and yield strength of the carbon steel MIG/MAG welding electrode can be found in AWS A5.18 (1993) and are respectively 480 MPa (70 kpsi) and 400 MPa (58 kpsi).

The admissible tension (σ_{adm}) of the electrode and the base metals vary with the type of loading and the type of welding performed, and for tensile loads in top-end welding, these are equivalent to 60% of the yield strength. This makes it possible to verify whether or not the welded joint will withstand the tensile stress applied since the mean normal stress (σ) must be less than or equal to the admissible stress (σ_{adm}) so that the applied load is supported without failures in the joint or in the joined components.

Using the information described above, a simple spreadsheet could be developed. Where the user enters data of units system (International or English), the dimensions of "h" and "l", the load "F" and the materials to be joined, and the spreadsheet returns the tensile strength and yield strength information, admissible tension for tensile loading, safety coefficient "n" which are the ratio between (σ_{adm}) and (σ). The spreadsheet also returns whether the component will fail or not. Figure 2 shows the data entry sheet and feedback information to the user.

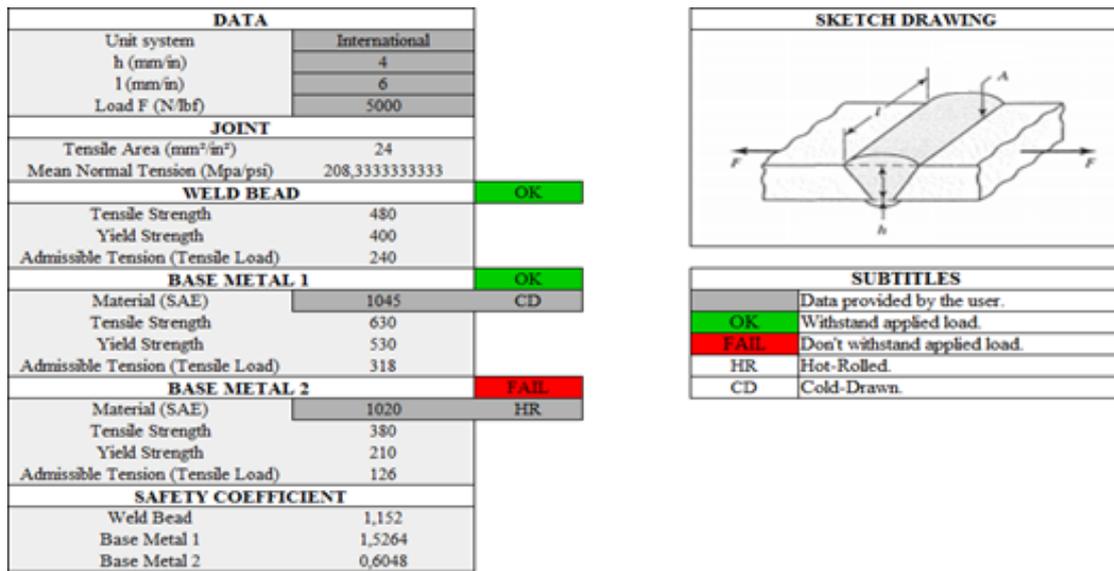


Figure 2. Spreadsheet main worksheet

2.2 Tensile test methodology

Tensile tests have many applications in the industrial environment and are a very import, mainly in the mechanical elements industry. This characteristic is because this test is capable of reporting relevant material data, such as tensile strength and yield strength, as well as modulus of elasticity, resilience and toughness. The specimens in this test are subjected to gradual deformations until they reach the rupture stress. Tensile test summarized in an application of a crescent uniaxial tensile load. The test must be conducted according the ASTM E8/E8M norm (Timoshenko, 1996; Souza *et. al.*, 2012; Smith *et. al.*, 2013; Garcia *et. al.*, 2000).

To accomplish this work, steel plates with 4 millimeters of thickness was welded using the MIG process with 164 amperes and a wire with 1 millimeter of diameter.

Tensile tests and hardness tests was realized in the base metal to characterize it. Tensile tests also was realized in the welded joint specimens. The specimens was manufactured by water jet cutting to avoid the thermal effects generated by others machining methods. The test was realized in 10 specimens whose dimensions are shown in Fig. 3.

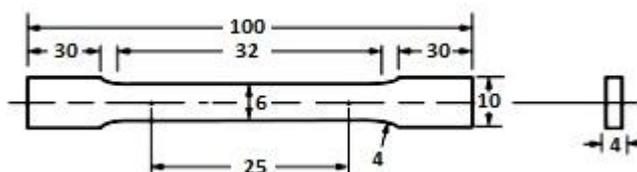


Figure 3. Specimens dimensions in millimeters, according the ASTM norm.

3. RESULTS

To show the results of this work in a clear way, the results were separated in two subsections. The spreadsheet results will be shown in the section 3.1 and the results of the tensile test will be shown in the section 3.2.

However, before analyzing the spreadsheet, it was necessary to analyze the results of the tests with the base metal. With these results, the base metal was labeled as a SAE 1006 steel.

3.1 Spreadsheet results

Inserting the data of the dimensions ($h=4$ mm, $l= 6$ mm) and the materials (SAE 1006 HR) of the specimens into the spreadsheet, to applied forces below or equal 2447 N the spreadsheet returns the “OK” value, that means that the welded joint will withstand the load, and to applied forces above 2447 N the spreadsheet returns the “FAIL” value, that means that the welded joint may present risks of rupture. Figure 4 shows an illustration of the spreadsheet completed with the values of the dimensions and materials of the specimen beside the returns of withstand or not withstand the load.

(a)	DATA		
	Unit system	International	
	h (mm/in)	4	
	l (mm/in)	6	
	Load F (N/lbf)	2447	
	JOINT		
	Tensile Area (mm ² /in ²)	24	
	Mean Normal Tension (Mpa/psi)	101,9583333	
	WELD BEAD		OK
	Tensile Strength	480	
	Yield Strength	400	
	Admissible Tension (Tensile Load)	240	
	BASE METAL 1		OK
	Material (SAE)	1006	HR
	Tensile Strength	300	
	Yield Strength	170	
	Admissible Tension (Tensile Load)	102	

(b)	DATA		
	Unit system	International	
	h (mm/in)	4	
	l (mm/in)	6	
	Load F (N/lbf)	2448	
	JOINT		
	Tensile Area (mm ² /in ²)	24	
	Mean Normal Tension (Mpa/psi)	102	
	WELD BEAD		OK
	Tensile Strength	480	
	Yield Strength	400	
	Admissible Tension (Tensile Load)	240	
	BASE METAL 1		FAIL
	Material (SAE)	1006	HR
	Tensile Strength	300	
	Yield Strength	170	
	Admissible Tension (Tensile Load)	102	

Figure 4. (a) “OK” situation for applied load of 2447 N (b) “FAIL” situation for applied load of 2448 N

3.2 Tensile test results

The results inherent to the tensile test were obtained and analyzed. The results most distant from the average were discard. These values are listed in Tab. 2, considering the mean of these results and the standard deviation. Fig.5 shows the Stress x Strain plot of the test bodies tested.

Table 2 - Experimental results of the tensile test.

	Maximum Force (kN)	Maximum Tension (MPa)	Breaking Deformation (mm)	Yield Strength (MPa)	Young's modulus (MPa)
Mean	7,664	271,2	12,14	146,2	3207
Median	8,070	288,7	11,77	153,9	3265
Standard Deviation	1,190	42,59	1,188	53,81	419,1
Variability (%)	15,53	15,53	9,781	36,8	13,07
Minimum	7,104	254,2	11,33	103,2	3049

It can be observed that the values obtained from the experimental tests were higher than those calculated by the spreadsheet. This is because, the calculation tool used methods of lowering the maximum supported tension, so that the component is dimensioned supporting a tension less than the real one. Considering the yield stress obtained by the experimental tests, an oversizing of approximately 1.45 was obtained with respect to the calculated maximum load that the component supports.

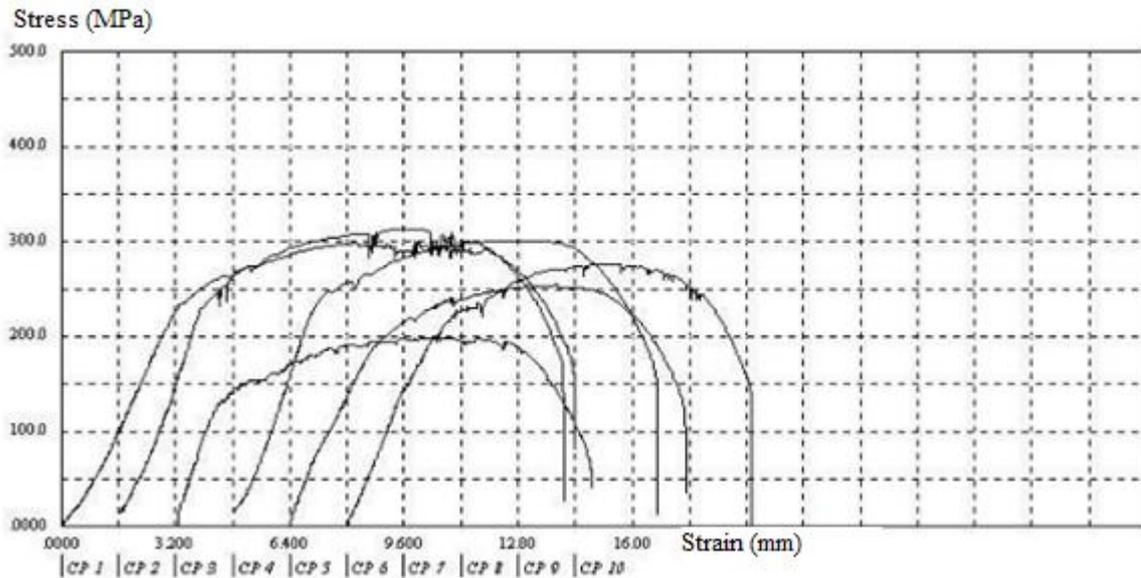


Figure 5. Stress x Strain plot of the specimens

It is also noticed that, according to the spreadsheet, the base material is the one that will fail first. This effect is because the steel has a lower permissible stress than the projected weld. This event was evidenced when conducting the tensile test, once no specimens broke in the weld, but in the base material. Figure 6 shows the fractured specimens.



Figure 6. Fractured specimens

4. FINAL CONSIDERATIONS

The development of this work was of great importance to validate the spreadsheet developed, once this can save time in designing a welded joint exposed to tensile stresses. Thus, it makes automatic the search for values of tensile strength and yield strength in tables, as well as the application of correction and safety factors for them. Once the worksheet returns the values of "OK" or "FAIL", it is enough for the user to evaluate whether it will be necessary to decrease the load or increase the area of tensile strength.

The spreadsheet developed allows only pure tensile stresses to be evaluated, once it was developed considering comparisons with mechanical tests, and only tensile tests were feasible to perform because of the available equipment. Therefore, it is suggested that for future work a tool is developed that allows analyzing, in addition to tensile stresses, bending, shearing and fatiguing.

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