PRE-VALIDATION OF WELDED JOINTS IN A BIKE FRAME

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ABSTRACT

In many industrial situations, it is necessary to prove that a certain product meets quality requirements even if it is not yet produced. For the present case, is it necessary to verify that an automated weld procedure for bike frames, different from the conventional, meets the structural strength requirements imposed by an international standard. However, due to the extent of automation required, it is impossible to produce at least one bike frame in order to test it. For preliminary validation proposes and to optimize welding parameters, it was proposed to perform tests on specimens.

This work presents a procedure to verify if the welded joints meet the requirements of EN14766 standard in terms of fatigue strength, by testing specimens. The bike frame geometry was analysed using the finite element method with the loads and constrains defined by EN14766 standard. From this model it was possible to indentify which joins were critically loaded and their respective acting loads. A special griping device was designed for a single axis servo-hydraulic testing machine in order to apply normal loads and bending moments similar to the ones calculated. Several H shaped welded specimens were fatigue tested and the results shown that this automated welding procedure is able to meet EN14766 standard requirements in terms of fatigue resistance.

KEY WORDS: Fatigue testing, EN14766, Weld, Finite Element Method.

1 INTRODUCTION

Usually one of the most important constrains in production is the time necessary to develop and implement a production line with capacity to assure the final quality of the product. Nowadays all these steps take a long time, considering the automation level used, but it will be rewarded in production time. If the production procedures are not well defined or detailed, this can lead to the reprogramming of the entire production line or dimensioning of the entire project.

In the particular case of welded joints, all the procedure must be optimized, ensuring that the quality and mechanical resistance requirements, imposed by law or by the client, are granted. When we are talking about a larger production volume, another issue is the time to make a weld. In a bike frame, where there are about fifteen welding joints, all seconds are precious! When there is a production target of 1.000.000 frames. Only 1 second more on each weld will make the production target to delay 23 months (considering only one production line).

The bike frame welding is usually made using the TIG process but in this case it was used the MIG process that have been robotized to improve the quality. So that this process can be accepted by the client it is necessary to fulfil the client’s requirements. The static mechanical resistance will be ensured by traction tests to shaped H specimens. Thought this analysis it was possible to optimize the welding process under static loading, however, this is not sufficient to ensure that the bike frame can support dynamic loads without fatigue damage.

Norm EN14766 [1] defines dynamic tests to be performed on a bike frame. These consider the simulation of three different loading cases (pedalling, horizontal load and vertical load, figures 1, 2 and 3 respectively) to apply on the bike frame.

The production costs of a bike frame for fatigue testing are tremendous considering that all the robots for automated production must be programmed. Programming a welding procedure for a specimen is much less time and cost consuming. The specimen also allows changing quite easily welding setup that will give new characteristics to the welded joint, allowing optimisation.

According to the norm EN14766, [1] three different fatigue tests are required to the bike frame that can be simulated in specimens. Each represents a different situation that the bike suffers during its circulation. The first one (figure 1) simulates the pedalling loads. It is composed by two forces of 1200N, applied on each pedal alternately. These forces are applied on a device that simulates the pedal position, and made a 7,5º angle with the vertical when the bike is observed from the front. In each cycle there are two applied forces, one on each pedal. This difference happens because of the chain positioning that supports some of the load transmitted to the bike framed by the pedal forces.
In the second test a horizontal load is applied to the bike's fork (that can be considered rigid), maintaining the rear wheel support fixed, as shown in figure 2.
In the third test (figure 3) a vertical load is applied to the bike frame using a device that represents the cyclist seat. Each one of these tests has a total of 50000 cycles, making a total of 150000 cycles to the bike frame. At the end of all tests the bike frame should not present any traces of fatigue cracks.

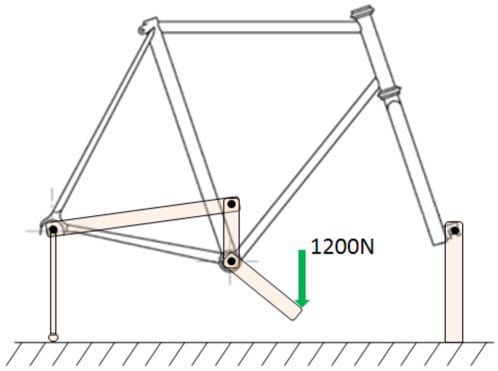

Figure 1. Test 1 (Pedalling).

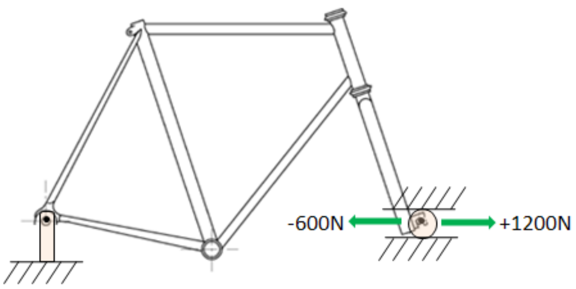

Figure 2. Test 2 (Horizontal Load).

The objective of this work is to validate a welding procedure verifying that it ensures the norm EN14766, [1] requirements. At this time is economically impossible to build a bike frame, the validation of the process will be made by specimen's testing. The specimens used are H shaped and welded using the same parameters to weld the bike frame and will be submitted to similar loads to those calculated in the bike frame, resulted by the tests previously defined. The similar loads will be obtained by the finite element method using the software Cosmos M [6], analysing the tests defined in norm EN14766, [1].

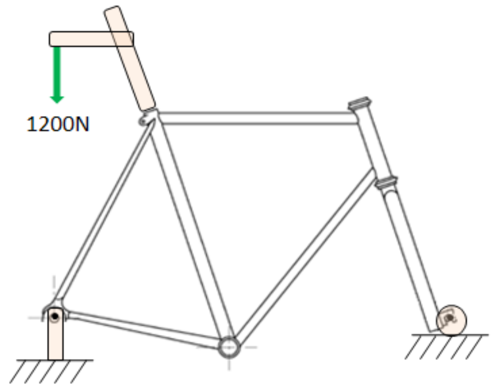

Figure 3. Test 3 (Vertical Load).

2 FINITE ELEMENT MODEL

The bike frame analysis was preformed by the finite element method using the finite element code CosmosM [6]. The structural discretization was throughout three-dimensional two-node beam elements (beam 3d CosmosM element) with six degrees-of-freedom per node: three displacements, u, v and w, respectively in x, y and z directions, and three rotations, Θ_x, Θ_y, and Θ_z, respectively about x, y and z axis.
Figure 4 represents the 12 degrees-of-freedom of the beam element as well as the local coordinate system.

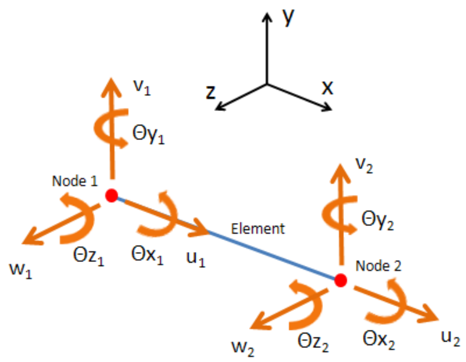

Figure 4. 3d Beam Element.

The bike frame was discretized by 149 beam elements. The linear parts of the frame were discretized by only one element each. For the discretization of the curve parts of the frame it was used several elements in order to fit the geometry to be as close as possible to the real one.

In order to determine which one of the joints, identified in figure 5, is the critical one, it was used the Miner rule that allows to calculate the damage that each section suffer when it is subjected to combined loads [2, 3 and 4].

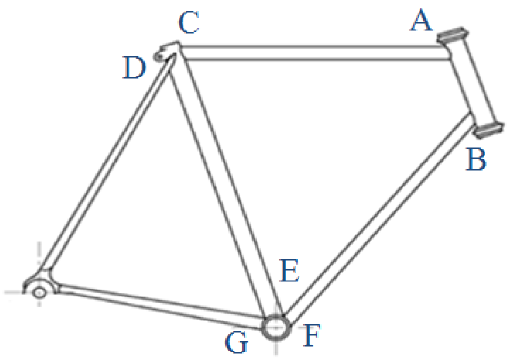

Figure 5. Welded joints analyzed.

To estimate the number of cycles that would lead to failure, it was used the Basquin's Law with general Al6061T6 properties [5].

$$N = \left(\frac{\sigma_a}{a}\right)^{1/b} \tag{2}$$

where σ_a is the equivalent alternated stress to the structural element in analysis.

The constants a and b are calculated as:

$$a = \frac{(0{,}9S_{ut})^2}{S_e} \tag{3}$$

$$b = -\frac{1}{3}\log\left(\frac{0{,}9S_{ut}}{S_e}\right) \tag{4}$$

where S_e is the Fatigue Strength and S_{ut} is the Ultimate Tensile Strength.

We may note that the objective is to calculate which section is the critical one and not the component's life.

The equivalent alternated stress was calculated using the values of the alternated and medium stress in the following Goodmans's equation:

$$\sigma_{eq.alt} = \frac{\sigma_{alt}}{1-\dfrac{\sigma_{med}}{\sigma_{yield}}} \tag{5}$$

where $\sigma_{eq.alt}$ is the equivalent alternated stress, σ_{alt} is the alternated stress, σ_{med} is the medium stress and σ_{yield} is the yield stress of the material.

The values of Medium Stress, Equivalent Alternated Stress and Maximum Stress as well as the damaged, obtained for each one of the joints of figure 5, corresponding to the different tests, are presented in table 1. The sum of all the damage in each joint is also represented.

According to table 1, the critical section is the section named G, identified in figure 5, because it has a higher damage value. The critical section is located in the lower right arm of the back wheel (figure 6). This section will provide the loads to apply on the testing specimens. From the three different tests defined by the norm EN14766, [1], the one that contributes more to the damage in this section is the test 1 that simulates the pedalling forces. For an easier perception is possible to see a detail from the critical section in figure 6.

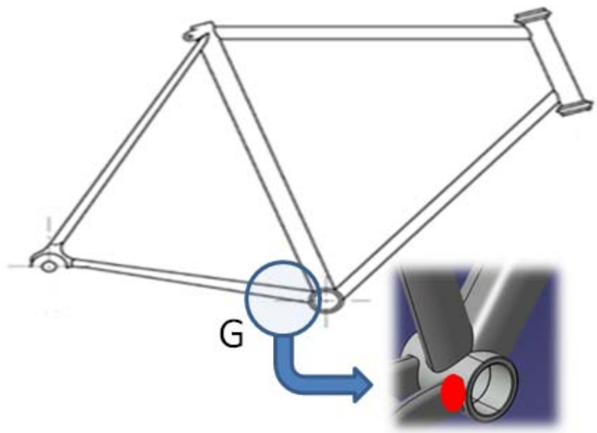

Figure 6. Critical section.

There are other sections that are critically loaded such as section E and A that present values of damage close to damage values of the section G, 0,10 and 0,07% respectively.

Table 1. FE Analysis results.

	Section	A	B	C	D	E	F	G
Test 1	Medium Stress [MPa]	22.68	25.11	9.54	17.62	41.48	13.73	43.88
	Eq. Alt. Stress [MPa]	24.90	27.86	9.92	18.92	49.53	14.51	53.00
	Damage	0.0000	0.0000	0.0000	0.0000	0.0010	0.0000	0.0017
Test 2	Medium Stress [MPa]	39.68	7.41	16.53	0.40	29.92	27.87	13.21
	Eq. Alt. Stress [MPa]	46.99	7.63	17.68	0.40	33.89	31.29	13.93
	Damage	0.0006	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Test 3	Medium Stress [MPa]	5.79	1.87	1.97	9.94	4.17	2.80	6.72
	Eq. Alt. Stress [MPa]	5.92	1.88	1.99	10.34	4.24	2.84	6.90
	Damage	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total Damage [%]		0.07	0.00	0.00	0.00	0.10	0.00	0.17

3 SPECIMENS

The H shaped specimens used in the fatigue testes, are represented in figure 7.

Figure 7. H shaped welded specimens.

These specimens were obtained by a robotized MIG welding process, which will be used on the bike frame construction. As it can be seen in figure 8, the specimens are made with three aluminium tubes with two circular welds. Initially some specimens were statically tested in order to optimize the welding parameters, including time, with the requested mechanical strength.

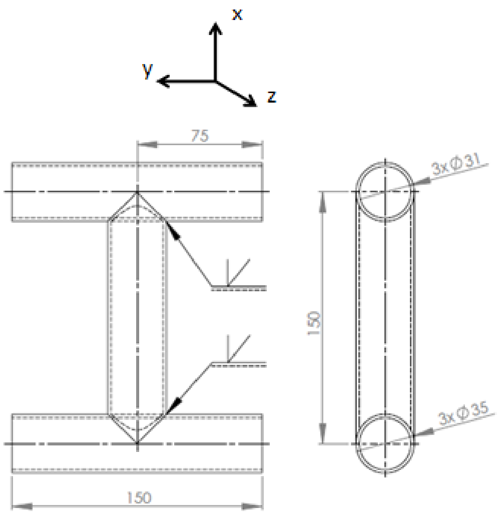

Figure 8. H shaped welded specimen.

The material used on the specimens is the Aluminium alloy AL 6061. The specimens suffered a heat treatment (T6) after welding, which cycle is represented in figure 9.

4 LOADS TO APPLY ON THE SPECIMEN

After the finite element method study, the loads to apply to the specimens were calculated. For this it was considered that the testing machine used to perform the fatigue tests is uniaxial and does not allow the application of shear loads.

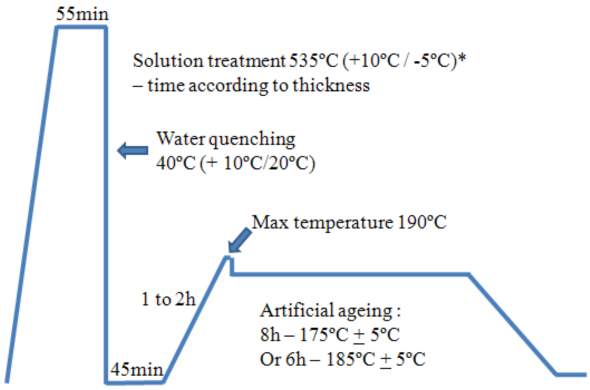

Figure 9. Heat Treatment T6 for Al6061 alloy.

The normal load to be applied to the specimen was calculated by:

$$N_{spec} = \frac{\sigma_{Neq}}{A_t} \tag{6}$$

where A_t is the resistent area of the specimen and σ_{Neq} is a Von Mises equivalent stress given by:

$$\sigma_{Neq} = \sqrt{\sigma_{Fr} + 3.(\tau_{Vt} + \tau_{Vs} + \tau_{Tr})} \tag{7}$$

where σ_{Fr} is the stress due to the normal load Fr, τ_{Vt} is the stress due to shear force in Y direction, Vt, τ_{Vs} is the shear stress due to shear force in Z direction, Vs, and τ_{Tr} is the shear stress due to torque, Tr.

The values fo these stress components were obtained througtout the finite element analysis of the bike frame.

To obtain the bending moments about y and z axis, the normal load (N_{spec}) was applied and the specimens were misaligned in directions z and y, respectively (axis reference in figure 8). The misalignement values Y and Z were calculated so that the same stress values due to bending moments obtained by finite element analysis for the critical section were introduced on the specimens:

$$Y = \frac{\sigma_{Mz}.I_t}{N_{spec}.r_t} \tag{8}$$

$$Z = \frac{\sigma_{My}.I_t}{N_{spec}.r_t} \tag{9}$$

where I_t and r_t are, respectively, the second moment of area and the outside radious of the tube cross-section used on the specimens.

In table 2 are presented the normal load values and the misalignement values to apply on the specimens for each one of the fatigue tests to be done.

Table 2. Loads to be applied on fatigue tests.

	Test 1	Test 2	Test 3
Fmax [KN]	6.71	3.80	1.92
Fmin [KN]	0.67	-1.90	0.19
Fmed [KN]	3.69	0.95	1.06
Falt [KN]	3.02	2.85	0.86
Y [mm]	-5.75	-5.77	3.99
Z [mm]	-11.26	3.31	4.56

For the tests were load ratio was R=0, it was considered R=0.1, to avoid problems with any possible mechanism clearance in the testing machine.

In order to ensure that the norm EN14766, [1], requirements are fulfilled, the specimens has to resist 50000 cycles for each one of the tests without any failure or visual evidence of fatigue cracks.

5 FATIGUE TESTS

The fatigue tests were made on a servo-hydraulic machine Instron 1342 (figure 10) equipped with a load cell +/-250KN and a digital controller Instron Fastrack 8800. This machine has only one actuation axis and can apply dynamic loads to the specimens.

Figure 10. Servo-hydraulic testing machine.

It was necessary to build a clamping system (figure 11, table 3) to the fatigue tests so that it could be possible to aplly axial loads and bendings at the same time with similar stress values to the ones obtained in the critical section from the bike frame analysis. The bending moments are created by the normal load and by the misalingnemt of the specimens in directions yy and zz.

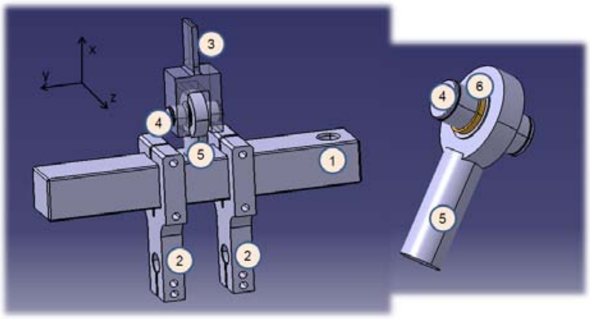

Figure 11. Clamping system.

In figure 12 it is possible to see a specimen already in test using the clamping system, with some visible misalignment in zz direction to create bending in yy direction.

Table 3. Clamping system parts.

Nº	Description	Amount
1	Clamp	2
2	Specimen support	4
3	Machine coupling	2
4	Pin	2
5	M36 Rod End	2
6	Spacing Ring	4

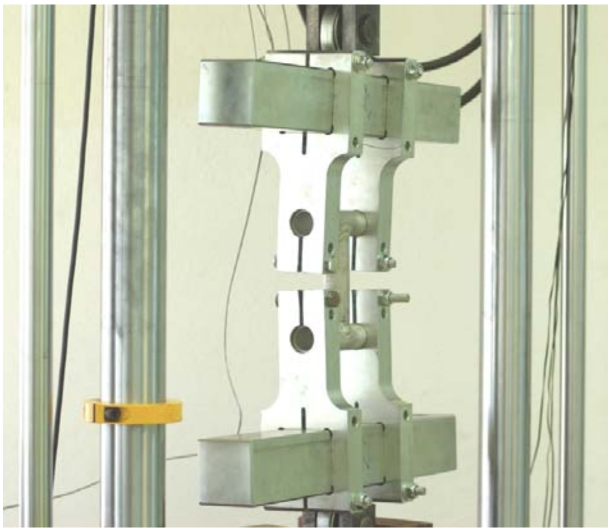

Figure 12. Testing specimen mounted in the testing machine.

6 RESULTS

During the fatigue tests, the specimens were observed several times in order to identify the possible fatigue cracks. Afterwards the specimens were observed with a binocular magnifying glass, in a microscope that allowed a detailed analysis of the specimen’s surface, and a liquid penetrant test (figure 13) according [1]. Any cracks were found during and after the fatigue test.

Figure 13. Liquid Penetrant Testing.

7 CONCLUSIONS

The resulting loads and stresses, from the three different tests defined in norm EN14766, were calculated using the finite element method. By this analysis it was possible to identify the critical section of the bike frame that is located in the lower right arm of the back wheel.

Several tests were made in H shaped specimens that represent the welding process used in the bike frame production. The loads applied by a testing machine in the specimens were determined to reproduce the stress field applied in the bike frame. In both specimens that were tested, no one had any evidence of fatigue or fatigue cracks after the 150000 cycles (50000 test 1 + 50000 test 2 + 50000 test 3).

The procedure used to test a specimen instead of an entire bike frame is correct, although some calculations are needed on the bike frame and some special devices such as clamping systems must be developed so that the fatigue tests can be successfully made. This procedure is justifiable when is necessary to make a previous evaluation about a welding process or when is necessary to approve a procedure. It is much more economical than build the entire bike frame and test it.

Based on this procedure, the specimen's test, in spite of being a good indicator of the fatigue resistance, does not dismiss the full bike frame test according to the norm EN14766. The welding fatigue resistance is dependent on weld geometry and quality, and that cannot be always assured, specially in difficult access joints.

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