METHODOLOGY FOR CLAMPING LOAD MEASUREMENT OF LOCKING SYSTEMS BASED ON WHITE LIGHT DIGITALIZATION

Carlos Javierre[a] (carlos.javierre@unizar.es)

Isabel Clavería[a,*] (Isabel.claveria@unizar.es)

Jorge Santolaria[b] (jsmazo@unizar.es)

Daniel Elduque[a] (danielduque88@gmail.com)

[a]Mechanical Department, University of Zaragoza EINA, Maria de Luna 3 50018 Zaragoza, Spain

[b] Department of Design and Manufacturing Engineering, University Of Zaragoza EINA, Maria de Luna 3, 50018 Zaragoza, Spain

* Corresponding author isabel.claveria@unizar.es +34649116405, fax:+34976761861

Abstract

This paper presents a new methodology to measure clamping force of locking elements of a weatherproof luminary from the previous determination of its stiffness and the stretching it suffers under assembly conditions. Application of the methodology includes determination of the clips stiffness both experimentally and by FEM analysis, and measurement of the stretching by white light digitalization techniques.

Elongation values measured by white light are similar to those analyzed by conventional methods. The relationship between clips elongation and load applied is linear, so stiffness can be deduced from the slope of the curve. Results show that functionality of the clips can be achieved with different values of stiffness. There is not any direct relationship between clip stiffness and load performed by them because of the influence of initial length on the final load performed. Therefore, manufacturing tolerances must be taken into account to assure the proper performance of the clips.

Keywords: weatherproof joint, load measurement, white light measurement, stiffness, elongation measurement.

1.- INTRODUCTION

When developing mechanical components, it is essential to know working conditions under which it is going to be subjected along its working life to be able to make the proper calculations from this information in order to determinate its technical viability.

Leak-free o weatherproof luminaries are lighting systems used all around the world both for industrial and domestic purposes [1-2]. Weatherproof luminaries have an outer cover to protect the electrical and lighting devices from impacts and from physical and chemical agents that are present in the environments where luminaries are allocated, see figure 1. In many cases the kind of lighting is fluorescent, although nowadays LED technology-based is increasingly used [3].

Figure 1: Sample cases of weatherproof luminaries.

According to figure 2, main components of a weatherproof luminary are the outer cover formed by two elements: a transparent or translucent diffuser (1) and an opaque housing (2); the sealing performance is achieved thanks to locking clips (3); a flexible gasket (5), and the lighting system (4), usually assembled on a metallic tray.

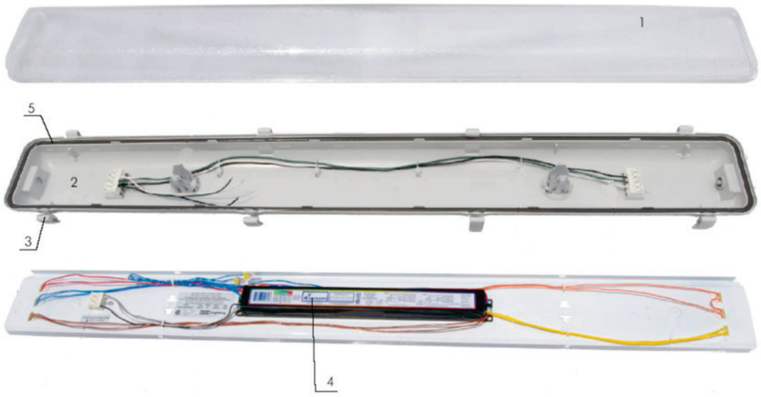

Figure 2: Elements of a weatherproof luminary.

For tensile joints, the theoretical sealing performance is guaranteed by the compression of the elements that form the joint generated by the initial clamping force [4]. For a luminary, the initial clamping force is achieved by the locking clips, which compress a polyurethane (PU) gasket located between the housing geometry and the diffuser rib as seen on figure 3. An optimum sealing performance depends on the proper contact between the diffuser and the gasket propitiated by a proper design of it [5], and the compressive clamping force applied.

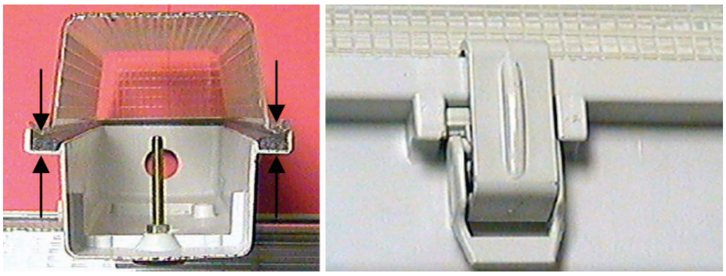

Figure 3: Sectional view of the elements intervening on the sealing (left) and locking clips performing the clamping force

By means of the locking clip, the gasket remains compressed, assuring a sealing performance. The only element that prevents environmental agents from entering into the luminary is the gasket. The sealing is kept if the compression of the gasket is guaranteed by the clamping force exerted by the clips [6]. The level of gasket compression depends on both the stiffness of the elements involved in the joint (clips and cover), and the initial clamping force as described on [7].

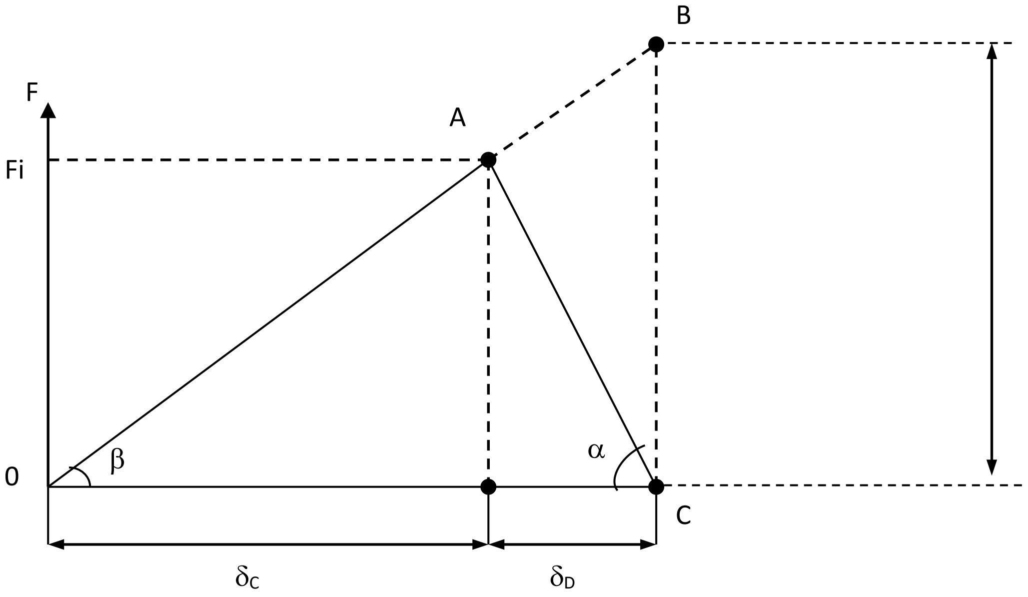

Figure 4: Theoretical principle of tensile joints

Figure 4 describes the stiffness distribution between the elements involved in the joint and its influence on the stretching of the clip and compression of the diffuser-gasket subassembly. $Tan\beta$ stands for stiffness of the clip, and $tan\alpha$ stands for stiffness of the cover-gasket sub-assembly. Point A stands for an assembled position of the clips performing an enough clamping force Fi to keep the gasket compressed. δ_C is elongation length of the clip due to assembly situation A and δ_D is compression length of the gasket due to clamping force on situation A.

The locking clip is very important for the proper functionality of the tensile joint of the luminary and its design is a critical point for the development of these components [8]. The design process includes determination of the load that must apply the locking clip, and the suitable design of housing, diffuser, gasket and clip to achieve desired load. A clamping force lower than a proper one does not guarantee the sealing of the luminary, and a very high load could cause damage on the housing and diffuser as shown on figure 5, or lead to clip failure.

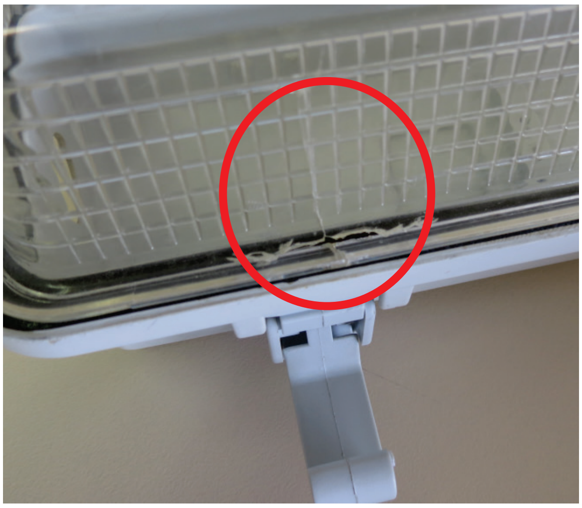

Figure 5: Diffuser damaged due to excessive clamping force

Clamping force depends on the real dimensions of the different elements (diffuser, housing and gasket), and these real dimensions are conditioned by their tolerances [9]. From figure 6, it can be observed that the clip remains stretched a length generating a clamping force proportional to this elongation after assembling. The exact value of the clamping force can not be known, nor adjusted during the assembly process as it depends of the real dimensions of the components taking into account the tolerances.

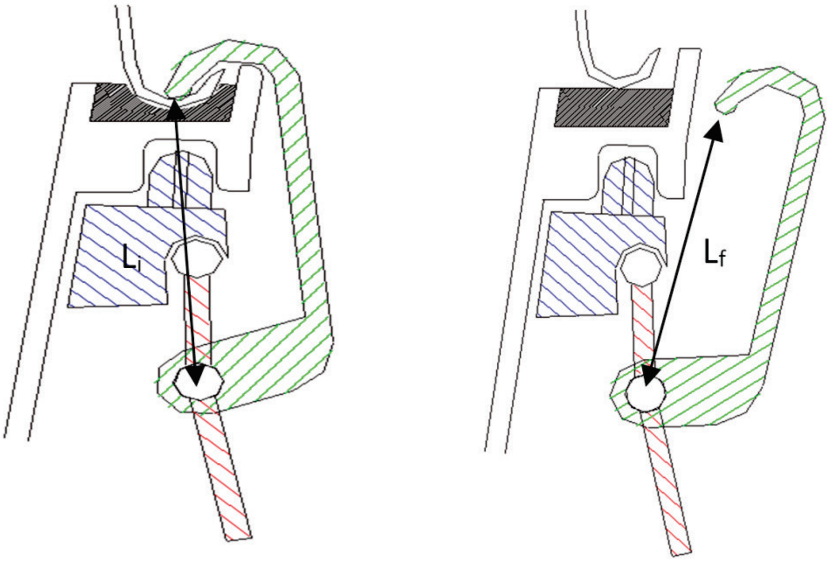

Figure 6: General geometry of a clip

By means of CAE techniques clamping force could be calculated theoretically from ideal geometries, and tolerances could even be taken into account for such calculations [10]. However a more realistic way of calculating the clamping force should include a measurement of the real increment of length produced in the clip and a previous calculation the clip stiffness. Experimental measurement of the real clamping force after assembly allow to validate the theoretical calculations and to guarantee the proper design of the clip. To carry out such measurements and calculations different techniques can be used such as traditionally contact measurement methods [11], based on optical methods [12-13], or on tunneling effect [14].

This paper presents a new methodology of measurement of the clamping force to which a locking clip of a tensile luminary is subjected from the previous determination of its stiffness and the stretching it suffers under assembly and working conditions.

The main goal is to develop a methodology to measure the real clamping force made by locking clips of a weatherproof luminary and to apply such methodology to different typologies of luminaries, including representative materials and geometries to be able to extrapolate the results to the widest range of luminaries as possible. Application of the methodology includes determination of the clips stiffness both experimentally and by FEM analysis, and measurement of the stretching by white light digitalization techniques hardly ever used for this kind of measurements. As a result, a validation of the clips design can be achieved as well as general conclusions that can lead new clips development.

2.- MATERIALS AND EQUIPMENT

2.1. Weatherproof luminaries analyzed. Models and materials.

Selected models for analysis have been designed, manufactured and delivered by Zalux S.L. They have been selected because they cover almost the whole range of materials and lighting techniques for housings of weatherproof luminaries. Models named PE, Alhama and Oleveon have a lighting based on fluorescence with diffusers made of polycarbonate (PC), Polymethyl methacrylate PMMA and Styrene acrylonitrile SAN, and housings made of PC and polyester reinforced with glass fiber. Locking clips for these models can be made of polyamide 6 (PA 6) or stainless steel. Another model analyzed has been named as Nextrema I whose housing is made of injected aluminum, PC diffuser and stainless steel clips. Figure 7 shows the components for each model.

Figure 7a: Alhama model

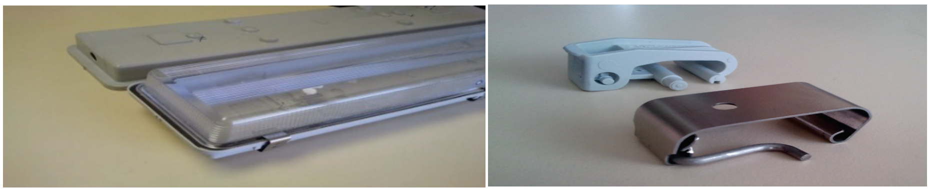

Figure 7b: PE model

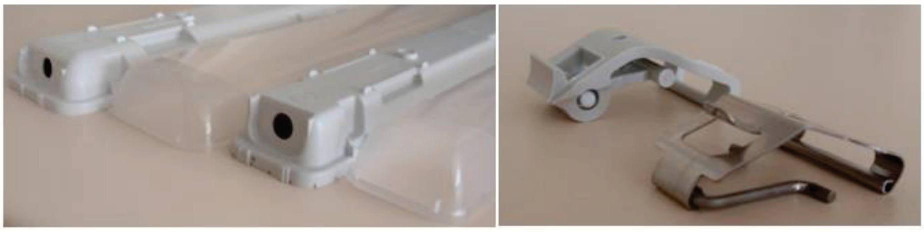

Figure 7c: OLEVEON model

Figure 7d: NEXTREMA model

The elements considered as critical from the point of view of the study are the locking clips. Regarding to material, the feature that determines the clips clamping force is the relation stress-strain. Table 1 shows Young Modulus for the materials used for the clips, 3000 MPa for PA6.6 and 210000 MPa for stainless steel. For the non-linear analysis, stress-strain curves supplied by the material manufacturer are used.

2.2. White light measurement system

A digitalization system by means of structured white light equipment that uses the technique of fringe projection [15-18] and phase shifting [19-21] is used to measure clips stretching dimension for both, assembled and non-assembled position. The system catches from a single capture a cloud of points from an area completely illuminated by the sensor. The fringe projection system used in this work is the Sidio PRO by Nub3D. Configured with a resolution of 0,075 mm, it is composed by a high intensity white light projector, which issues a structured light beam on the component, and a camera that catches the light on the component, registering the geometry.

The equipment has been configured and calibrated to work in a measure volume of 200x150x90mm. Equipment supplier defines a nominal accuracy of 0.015mm, according to VDI 2634 recommendation [22]. This configuration has been chosen in order to work under nominal accuracy conditions for the points caught, one order of magnitude below the expected elongations in the measured components.

After digitalization, a cloud of points will be obtained. All the points remain into a file type **.txt*, where the X, Y, Z coordinates from each point is registered. By applying the software Geomagic Qualify 12, the points are represented generating the digitalized global cloud of points which can be later treated.

2.3. CAE software

One way proposed for the calculation of the clips stiffness is based on the usage of finite elements CAE tools. For this research Solid Works 2013 from SolidWorks Corp. has been used. This software allows the introduction of 3D geometries as well as boundary conditions and loads thanks to the module SolidWorks needed to carry out the mechanical analysis.

2.4. Procedure

First, clips stiffness will be calculated by means of both, CAE tools and experimentally. To obtain the stiffness values, the elongation values of the clips under different loads will be measured by conventional methods to obtain load-elongation curves.

Secondly, the white light measurement method will be applied to take two measures of the clips, one assembled in the working position on the luminary and the other disassembled. Difference of these two measures will be the elongation suffered by the clip due to working conditions. By introducing this elongation value into load-elongation curves allows to calculate the load made by the clips from experimental curve of from CAE curve.

3. METHODOLOGY

3.1. Experimental measurement of stiffness

Clip stiffness is defined as the ratio between the load performed by the clip and the elongation suffered by it.

$K = F / \Delta L$ (1)

Where K is clip stiffness

F is applied load

ΔL is elongation measurement

Loads considered for clips design are usually about 3 Kg. Therefore, loads applied on the clips to measure the corresponding elongations will range from 0 to 6 Kg. Load will be applied from one kilo to one kilo by means of a set of one kilo weights. Measurement of the elongation will be defined between the contact points of the clip with the housing and the diffuser as described on figure 8 by means of a digital caliper.

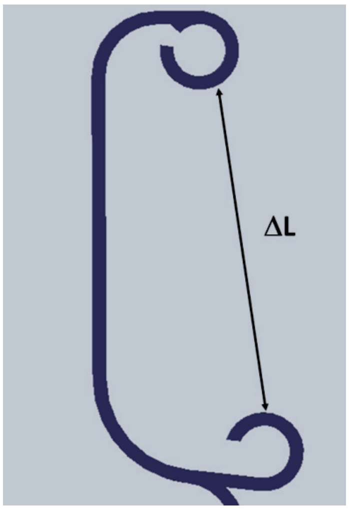

Figure 8: elongation measurement

Figure 9 shows the typical load-elongation curve obtained from the application of this methodology. It shows that the higher the applied load is, the higher the elongation is following a linear trend. The slope of the linear curve stands for the stiffness of the component.

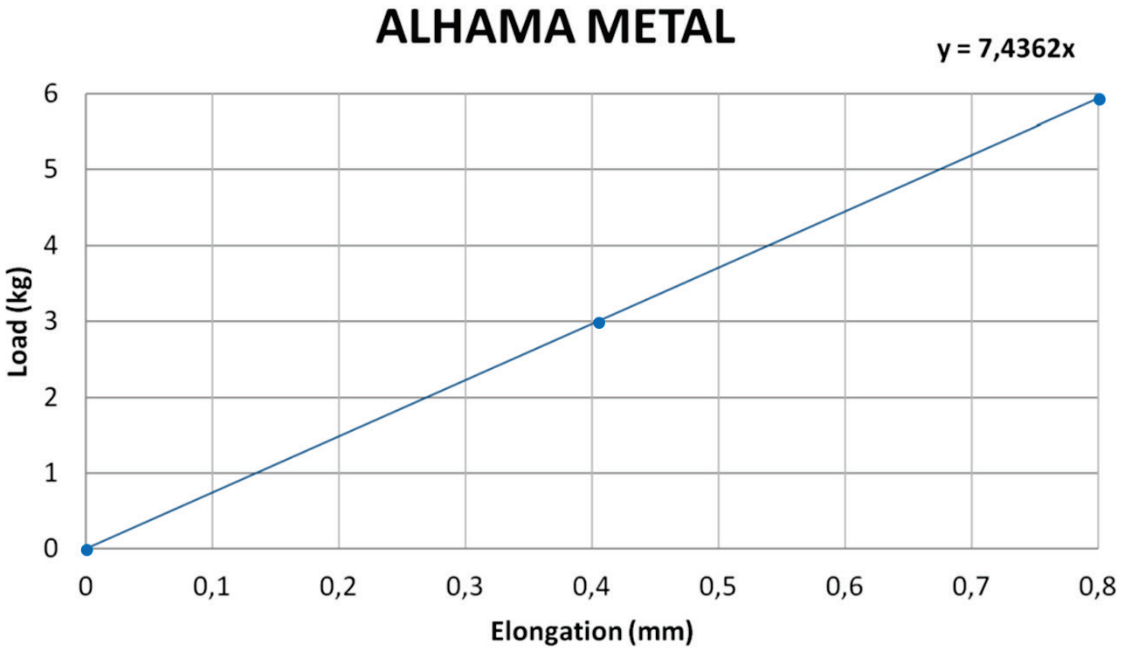

Figure 9: Experimental stiffness obtained for metallic clip of ALHAMA luminary model

3.2. Measurement of stiffness by CAE methods

The analysis begins from the nominal CAD model of each clip defined in SolidWorks. Contact surfaces between clip and both diffuser and housing are cylinder with diameters ranging from 2,8 mm (Oveleon model) to 5 mm (PE plastic model). For each model, an axis aligned with the direction of the applied load is defined. This direction is determined by joining the contact edge between the cylindrical curlers and the diffuser and housing, as shown in figure 10. Load is applied in one of the curlers and displacements are restricted on the other.

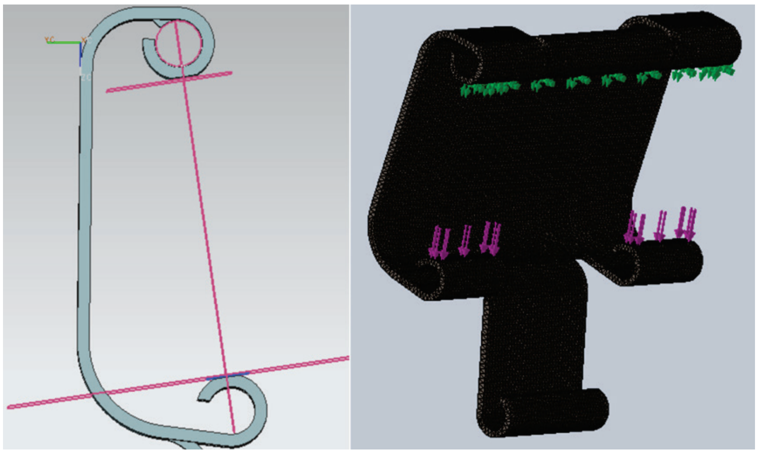

Figure 10: axis along load direction (left), edge location on the curler where loads and boundary conditions are applied (right)

Due to the linear relationship between load and elongation found in the experimental analysis, two study cases with loads of 3 Kg and 6 Kg will be analyzed. FEM model has a size element of 0,3mm. The result of the analysis is the value of displacements of the clip on the area where load is applied in the direction of load application. Figure 11 shows the results obtained. The configuration of boundary conditions used allows to establish the correspondence between the displacement result and the clip elongation.

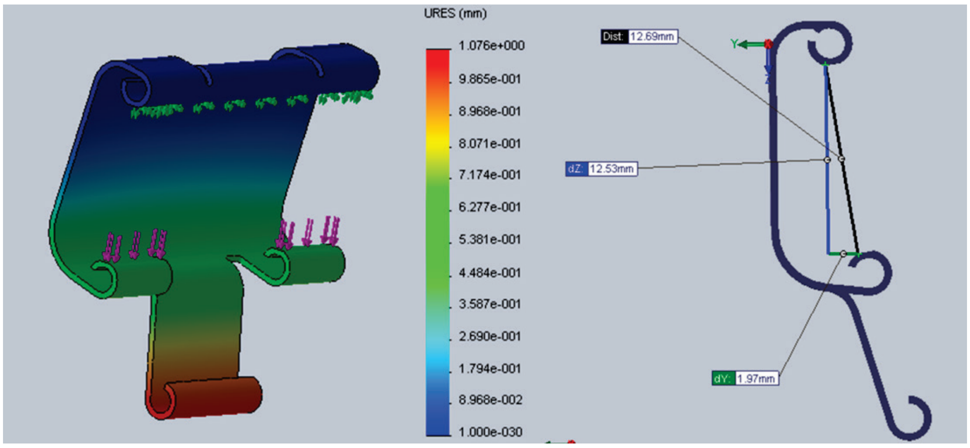

Figure 11: displacement calculated by CAE (left), components X, Y of the displacement (right)

3.3. Measurement of clip load by white light digitalization

In order to determine the load performed by the clip on the luminary under working conditions, it is necessary to measure the elongation suffered by it, and multiplying it by the previously calculated stiffness, according to equation 2.

$$F = K \, x \, \Delta L \qquad (2)$$

Where F is load performed by the clip to assure the sealing

K is stiffness calculated experimentally or by CAE methods

ΔL is elongation under working conditions measured by white light digitalization

To measure elongation by white light digitalization, it is required to catch the 3D object in unloaded position and later in working position assembled into the luminary. For these two positions, distance between contact points of clip with the luminary is taken. ΔL is given by equation 3

$$\Delta L = L_f - L_i \qquad (3)$$

Where ΔL is elongation

L_f is distance measured in working position

L_i is distance measured in unloaded position

The methodology to catch the 3D object is to take captures from different positions to later align them in order to get the object with all the 3D details. To achieve it, it is required the usage of markers, see figure 12, to allow the alignment with the software and the achievement of the complete cloud of points.

A first digitalization is carried out with unassembled clips measuring their free length. Once this first digitalization is finished, clips are assembled into their corresponding luminaries to be digitalized again, now in working position as shown in figure 12.

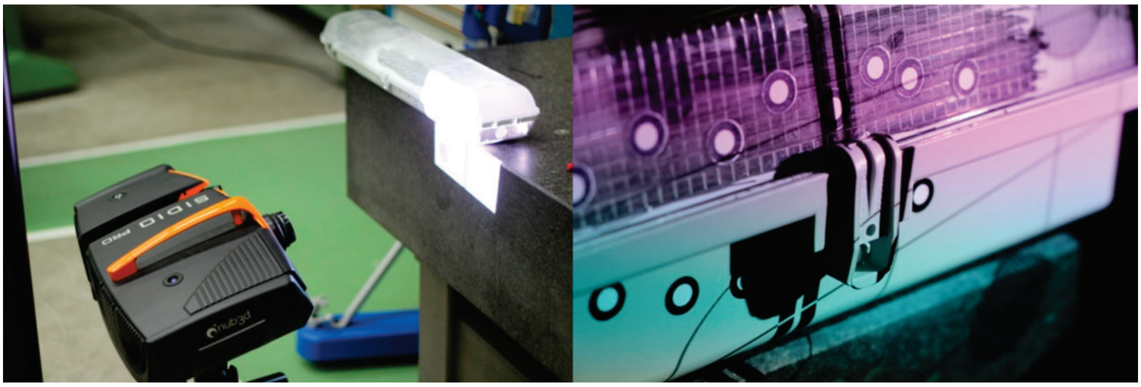

Figure 12: Digitalization of clip assembled, general view of Oveleon model (left) and detail view of PE model (right)

After finishing digitalization of all the clips, the cloud of points must be generated with the aid of the software Geomagic Qualify 12. Figure 13 shows the shadowed and unshadowed cloud of points generated.

Once the clouds are analyzed and the clips geometry are available, measurements of elongation of the clip can be taken. Distances from contact areas of the clip with both the luminary housing and the luminary diffuser are taken according to figures 13 and 14. Five different pairs of points along contact areas are measured to obtain an average value. First, the unloaded clip dimensions are checked in a comparison of the point cloud with the nominal CAD model of each part, in order to assess their manufacturing tolerances in the initial situation.

Applying this procedure to clips in unassembled position allows to obtain L_i value, and application to clips assembled in working position gives L_f value. Difference of these two values according to equation 3 gives the real elongation of the clip (ΔL).

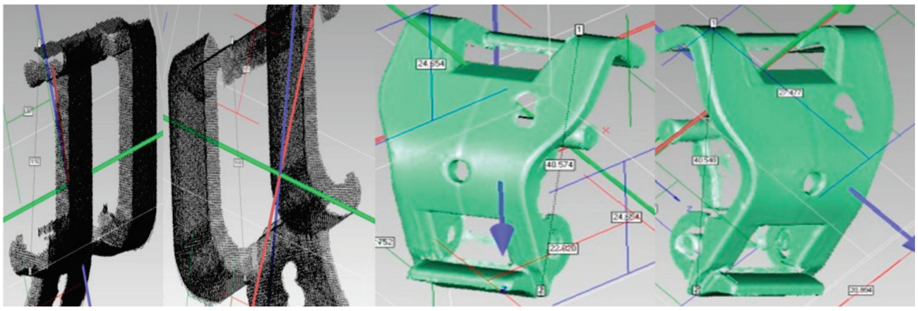

Figure 13: Measurement of the elongation on digitalized clips

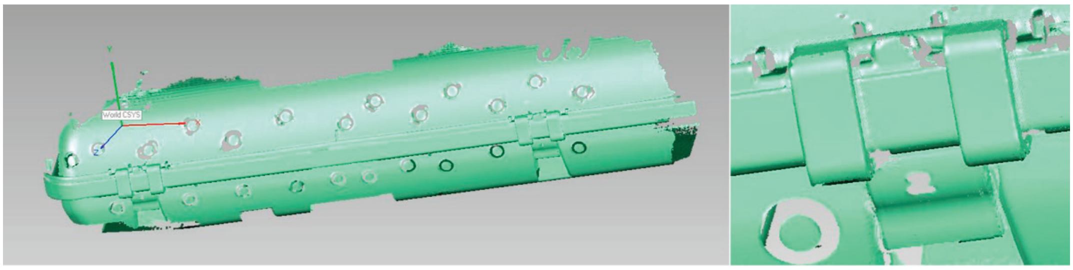

Figure 14: Digitalization of Alhama model with plastic clips

4. RESULTS AND DISCUSSION

4.1. Experimental and CAE stiffness of the clips.

Table 1 shows elongations suffered by all the clips when applying loads of 3 Kg and 6Kg, for both experimental and CAE analysis.

	EXPERIMENTAL (mm)		CAE (mm)	
	3Kg.	6Kg.	3Kg.	6Kg.
ALHAMA METALLIC	0,4	0,8	0,33	0,57
ALHAMA PLASTIC	0,32	0,55	0,27	0,5
PE METALLIC	1	1,85	1,23	2,21
PE PLASTIC	0,34	0,61	0,33	0,53
OLEVEON METALLIC	1,74	3,08	2,24	3,53
OLEVEON PLASTIC	1,3	2,7	1,3	2,25
NEXTREMA	0,09	0,18	0,09	0,18

Table 1: Elongation suffered by clips

From these results, the relationship load elongation can be represented according to figure 15. It can be observed that the trend is linear as expected, which allows to evaluate the stiffness from the slope of the linear curve. Results for stiffness are described on table 2.

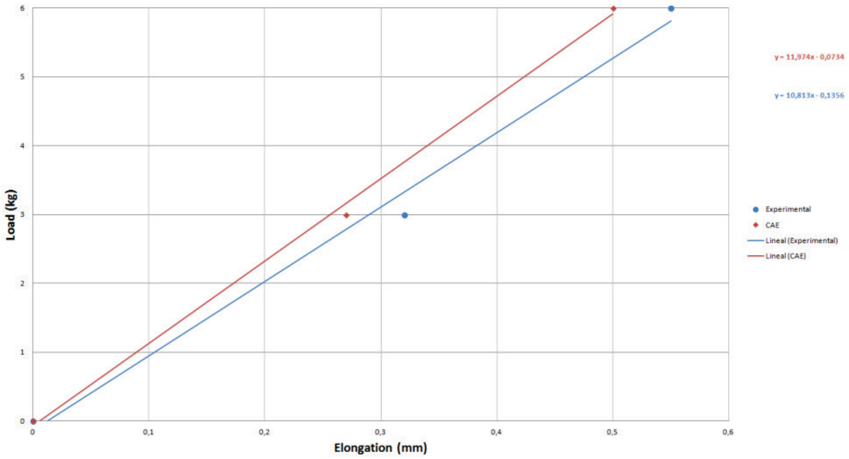

Figure 15: Load-elongation curve for Alhama model

	STIFFNESS Kg/mm	
	EXPERIMENTAL	CAE
ALHAMA METALLIC	7,5	10,16
ALHAMA PLASTIC	10,52	11,79
PE METALLIC	3,22	2,65
PE PLASTIC	7,11	10,69
OLEVEON METALLIC	1,89	1,6
OLEVEON PLASTIC	2,24	2,58
NEXTREMA	30,56	33,33

Table 2: Stiffness of the clips by experimental and CAE methods

For experimental stiffness values range from 1,89 kg/mm for the less stiff, (Oleveon metallic) to 30,56 kg/mm for the most stiff (Nextrema), and taking into account stiffness calculated by CAE methods values range from 1,6 kg/mm to 33,33 kg/mm. It means that high functionality clips can be designed with great differences of stiffness.

Differences between experimental values and values obtained from CAE analysis are lower than 15% for most of the models. The models whose differences between CAE and experimental are higher are Alhama metallic, Alhama plastic, and PE plastic because of the high stiffness of their design that implies very short elongations, so any minimum variation of elongation has a great influence on the stiffness value calculated.

For most of the models, the higher the clips are, the stiffer they are, and they correspond to those models made by a single part (Alhama and Nextrema models).

For the same model of luminary, plastic clips are more rigid than metallic ones in spite of the higher stiffness of metal regarding to plastic material. Stiffness of plastic clip from Alhama model is 40% higher than metallic clip. For PE model, plastic clip is 120% more rigid and for Oleveon model is 18 % stiffer.

All the clips exhibit a linear behavior regarding to stiffness, as demonstrated by the load-elongation curves.

4.2 Realistic load performed by the clips

Measurements of real elongation of the clips from white light method are shown in table 3. Results show an average value of the five pairs of points measured.

	ELONGATION (mm)
ALHAMA METALLIC	0,58
ALHAMA PLASTIC	0,52
PE METALLIC	0,84
PE PLASTIC	0,35
OLEVEON METALLIC	0,89
OLEVEON PLASTIC	1,05
NEXTREMA	0,1

Table 3: elongation measured by White light digitalization

Values obtained for elongation by white light digitalization method have an order of magnitude of 10^0 or 10^{-1}, which validates the accuracy of 0.015 mm used for the tests and previously described on "Experimental section".

From these values of elongation and stiffness calculated by CAE and experimental methods according table 2, load performed by the clips to keep the luminary sealed can be calculated from equation 2. Table 4 show load results.

	LOAD (Kg) (from CAE K)	LOAD (Kg) (from experimental K)	AVERAGE LOAD (Kg)
ALHAMA METALLIC	5,89	4,35	5,12
ALHAMA PLASTIC	6,13	5,47	5,80
PE METALLIC	2,2	2,70	2,46
PE PLASTIC	3,74	2,48	3,11
OLEVEON METALLIC	1,42	1,68	1,55
OLEVEON PLASTIC	2,70	2,35	2,53
NEXTREMA	3,33	3,05	3,19

Table 4: Load performed by the clips

Load values range from 1,55 Kg performed by model Oleveon plastic to 4,31 kg performed by Alhama metallic model. Load variation among different models is lower than variations of stiffness values.

There is not any direct relationship between clip stiffness and the load performed by them when assembled on the luminary. There is a parameter design of the clip, its initial length that has a great influence on the final load performed. For the most rigid clips variations in initial dimensions can lead to significant variations of the load performed. It implies that the clip can cause damage on the components where they are assembled when the load is increased, or the clip can not meet the sealing function when load is decreased. Therefore, manufacturing tolerances should be lower for the most rigid clips to assure the proper clamping force performed by the clips. Table 5 shows the average values of variations in initial length of 50 samples due to manufacturing process, and the load variation associated to the initial length variation. It can be observed importance of the variations, especially for Nextrema (more than 100%) and PE (up to 50%). Alhama and Oveleon models show more moderate variations between 14% and 24%.

	INITIAL LENGTH VARIATION (mm)	LOAD VARIATION (Kg)
ALHAMA METALLIC	0,12	0.9
ALHAMA PLASTIC	0.14	1.4
PE METALLIC	0.25	0.8
PE PLASTIC	0.22	1.56
OLEVEON METALLIC	0.15	0.28
OLEVEON PLASTIC	0.16	0.36
NEXTREMA	0.12	3.6

Table 5: Load variations due to initial length variations

5. CONCLUSIONS

A new method to measure clamping load of locking elements for weatherproof luminaries based on white light digitalization has been developed. The method has been applied to different models of luminaries and different materials for locking elements. White light digitalization is used to determine elongation of locking clips when assembled in working position. Values measured by white light are similar to those analyzed by conventional methods such as digital caliper or CAE systems.

The relationship between clips elongation and load applied is linear, so stiffness can be deduced from the slope of the curve representing this relationship. Results show that functionality of the clips can be achieved with different values of stiffness, regarding the initial design geometry of the clip. Designs achieving high stiffness imply very short elongations under load, so minimum variations of elongation have a great influence on the stiffness value calculated.

There is not any direct relationship between clip stiffness and the load performed by them when assembled on the luminary because initial length that has a great influence on the final load performed. For high stiffness clips, so manufacturing tolerances should be lower for the most rigid clips to assure the proper clamping force performed by the clips.

References

[1] http://www.zalux.com/ficheros/2014/Zalux_Product_Catalogue_2014-15.pdf, July 2014

[2] http://www.zalux.com/ficheros/2013/Components_Catalogue.pdf, July 2014

[3] Barkovsky, B. Vladimir, Lyakisheva, V. Inna, Stepanov, N. Vitaly, Led Luminaries And Lighting Applications, Light & Engineering 16 (2) (2008) 31-37

[4] J. H. Bickford, An introduction to design and behavior of bolted joints, third ed. and expanded, Marcel Dekker Inc.New York, 1995.

[5] J. Arghavani, M. Derenne and L. Marchand, Sealing Performance of Gasketed Bolted Flanged Joints: A Fuzzy

Decision Support System Approach, Int J Adv Manuf Technol 17 (2001) pp 2–10

[6] A.D. Deautschman, W.J. Michels, C.E. Wilson Jr, Machine Design: Theory and Practice, first ed., MacMillan, Michigan, 1975 pp 856-857

[7] J. Castany, A. Fernández, F. Serraller, Análisis de la funcionalidad de los elementos de máquinas, first ed., Prensas Universitarias de Zaragoza, Zaragoza 2000 pp 69-75.

[8] H. Kursat Celik, M.E. Lupeanu, A.E.W. Rennie, C. Neagu, I. Akinci, Product re-design using advanced engineering applications and function analysis: a case study for greenhouse clips, J. Braz. Soc. Mech. Sci. 35(3) (2013) pp 305-318.

[9] L. Liu, J. Zhang, K. Chen, et al., Influences of assembly parameters on the strength of bolted composite-metal joints under tensile loading, Adv. Compos. Mater. 22(5) (2013) pp 339-359.

[10] R. Kurosawa, T. Sawa, S. Nagata, et al., The Effect Of Clamping Force And Material Properties On The Tightness Performance A Flexible Box-Shaped Flange Bolted Joint, Proceedings Of The Asme Pressure Vessels And Piping Conference, 2 (2009) pp 61-68.

[11] J. Novak-Marcincin, V. Fecova, J. Barna, dimension control by CMM, Quality And Innovation In Engineering And Management 2011 pp.:147-150

[12] J. Santolaria, J.J. Pastor, F.J. Brosed, J.J. Aguilar, A one-step intrinsic and extrinsic calibration method for laser line scanner operation in coordinate measuring machines, Meas. Sci. Technol. 20 (2009) 045107

[13] M.A. Younes, A.M. Khalil, M.N. Damir, Automatic measurement of spur gear dimensions using laser light, part 2: measurement of flank profile, Opt. Eng. 44 (10) (2005) 103603; DOI:10.1117/1.2114987

[14] T. Shiramatsu, K. Kitano, M. Kawada, K. Mitsui, Development of measurement method for shape and dimension of micro-components - (Modification of the original measuring system, calibration of the probes and the results of dimensional measurements), JSME International Journal Series C-Mechanical Systems Machine Elements And Manufacturing 47(1) (2004) pp. 369-376; DOI: 10.1299/jsmec.47.369

[15] J. Geng, Structured-light 3D surface imaging: a tutorial, Advances in Optics and Photonics 3 (2011) 128–160

[16] E. Horn, N. Kiryati, Toward optimal structured light patterns, Image Vision Comput. 17(2) (1999) 87–97.

[17] P. Payeur, D. Desjardins, Structured light stereoscopic imaging with dynamic pseudo-random patterns, Image Analysis and Recognition, Lecture Notes in Computer Science, Vol. 5627 (2009) pp. 687–696.

[18] S.S. Gorthi, P. Rastogi, Fringe Projection Techniques: Whither we are?, Opt Laser Eng. 48(2) (2010) pp.133-140.

[19] J. Burke, T. Bothe, W. Osten, C. Hess, Reverse engineering by fringe projection, Proceedings of SPIE Vol. 4778 (2002) pp. 312-324.

[20] Y. Morimoto ; M. Fujisawa, Fringe pattern analysis by a phase-shifting method using Fourier transform, Opt. Eng. 33(11), (1994).3709-3714.

[21] Q. Kemao, Windowed Fourier transform for fringe pattern analysis, Applied Optics, Vol. 43(13) (2004) pp. 2695-2702

[22] VDI/VDE 2634: Optische 3D-Messtechnik. VDI/VDE-Richtlinie, Blatt 1-2, Beuth Verlag, Berlin

FIGURE CAPTIONS

Figure 1: Sample cases of weatherproof luminaries.

Figure 2: Elements of a weatherproof luminary.

Figure 3: Sectional view of the elements intervening on the sealing (left) and locking clips performing the clamping force

Figure 4: Theoretical principle of tensile joints

Figure 5: Diffuser damaged due to excessive clamping force

Figure 6: General geometry of a clip

Figure 7a: Alhama model

Figure 7b: PE model

Figure 7c: OLEVEON model

Figure 7d: NEXTREMA model

Figure 8: Featuring of each model

Figure 9: White light digitalization equipment

Figure 10: Cloud of points for the metallic clip Alhama

Figure 11: clip models for SolidWorks

Figure 12: elongation measurement

Figure 13: Experimental stiffness obtained for metallic clip of ALHAMA luminary model

Figure 14: axis along load direction (left), edge location on the curler where loads and boundary conditions are applied (right)

Figure 15: displacement calculated by CAE (left), components X, Y of the displacement (right)

Figure 16: Markers

Figure 17: clips for digitalization

Figure 18: Digitalization of Oleveon model clip in resting position

Figure 19: Digitalization of clip assembled, general view of Oveleon model (left) and detail view of PE model (right)

Figure 20: solid model treated Geomagic Qualify 12

Figure 21: Measurement of the elongation on digitalized clips

Figure 22: Digitalización del modelo Alhama con clips de plástico.

Figure 23: load-elongation curve for Alhama model

TABLE CAPTIONS

Table 1: Materials stiffness

Table 2: elongation suffered by clips

Table 3: Table 3: Stiffness of the clips by experimental and CAE methods

Table 4: elongation measured by White light digitalization

Table 5: load performed by the clips

Table 6: Load variations due to initial length variations