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EXPERIMENTAL AND FEM ANALYSIS FOR BIAXIAL STATIC AND FATIGUE BEHAVIOUR OF THE ALUMINIUM STRUCTURES OF ROLLING STOCK'S SEATS

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ABSTRACT

This paper concerns the numerical and experimental characterization of the static and fatigue strength of an aluminum structure of rolling stock's seats. A series of static and fatigue test on full scale structure has been carried out using a biaxial test machine specifically designed, built and located in the laboratory of A-Technology industry to investigate the static and fatigue strength. The experimental results have been compared with numerical ones showing a very good correlation. The present paper gives an overview of such experimental and finite element method investigations specifying the type of loading used in fatigue tests and in FEM analysis and the main results obtained.

Keywords: *Multiaxial fatigue, Full-scale, Fatigue test machine, Machine design.*

INTRODUCTION

The growing interest in the use of new materials such as, for example, new types of composites and new aluminium alloy has required improvement in evaluation techniques of most of structural design parameters, as those related to fatigue, fracture, buckling phenomena and so on. Consequently, many design techniques have been developed using either more complex analytical formulations or numerical methods. So it's necessary to support these theoretical analyses by experimental tests that should take in account the real specimen shape and size and load conditions. In fact the classic tests under uniaxial loads are no longer enough to supply a real mechanical characterization of real specimen and therefore research is now aimed towards the realization of machines for multiaxial testing [1-3].

The machine presented in this work, has been designed by the authors and manufactured in firm A-Technology S.p.A.. The activity's task has been to test an aluminium structure of rolling stock's seats under multi-axial static or fatigue loads. A series of static and fatigue test on full scale structure has been carried out using a biaxial test machine. The specimen has been subjected to loads applied in eight points along two normal directions in several conditions according to the NF F31-119 standard [4].

Stress and deformation fields developed on the structure during the tests are simulated using Finite Element Method (FEM) [5-7]. The predictions of load–displacement characteristics by FEM are compared with the experimental results showing a very good correlation.

MACHINE DESCRIPTION

The multiaxiality of the machine here presented and shown in figure 1, is intended as its capacity for applying load along two normal axes. The machine consists of two hydraulic cylinders, in two normal directions, hinged on supports rigidly connected at a steel structure essentially made up of HEB 140 beams, which have been opportunely welded and flanged, and the form and dimensions of which have been determined on the basis of considerations principally relevant to the necessity to assure a forced stiffness; in fact, if maximum loads are applied simultaneously to the specimen tested, the frame of the machine will not deform in any direction by more than 2 mm in respect to its rest position.

The maximum load is 20 kN for each cylinder. The overall dimensions are about 2600 x 2600 x 1400 mm^3, obviously not considering the hydraulic and electric control units; the machine is able to test specimens with a size up to 2300 x 1200 x 1000 mm^3.

For each direction the load test can be applied in four different points by four clamps. In fact the four clamps are linked by a lever system to their respective load-applying cylinders. This loading system allows independent deformations along different directions and assures that the normal load is uniformly distributed on the four points. In this way fatigue and/or static loads can be applied by just two hydraulic cylinders; moreover it is also possible to apply a static load in one direction and a fatigue load in the other one.

Fig.1 Global view of testing machine.

LOADS DISTRIBUTION SYSTEM

The machine allows the application of load both along the two normal axes x (transversal) and y (vertical), singly or simultaneously; in this last case they are completely independent from each other. Moreover the machine allows the application of an established fraction of the total load on a specific portion of the test article. In other words, the advantage of this approach is to obtain a machine that allows the application of load to the test article, in a localized way which will assure that it is distributed equally and eliminates all uncertainty connected to the distribution of the applied loads during the tests.

The loads are exercised by two oleodynamic cylinders, each of which is placed in correspondence with the centre lines of the two sides of the specimen; the load is transmitted through a system shown in figure 2 made up of an assembly of two groups of balancing elements, each of which essentially consists of superimposed plates of varying forms and dimensions, which are connected and articulated through sleepers. A first assembly is made up of two plates each of which has a central connecting hole, that, through an hook, connects them to the oleodynamic cylinder, and two holes, one at each end; each of the aforementioned latter holes is used for connection to the second assembly of balancing elements split into two subgroups of plates, each of which is composed of one plate, which realizes the final division of the load onto the four clamps positioned on one side of the specimen. Each equalizer has arms of equal length so that the load is divided up equally; it is easy to deduct that, by using a system of equipment with unequal arms, any type of load distribution can be obtained on each side of the test article. The aforesaid system assures the uniform distribution of the normal loads developed by the vertical and transversal oleodynamic cylinders on all four clamps acting on a side of the test article.

Fig.2 Loads distribution system.

TESTING

Static and fatigue tests were carried out on rolling stock's seats manufactured by A-Technology S.p.A. shown in figure 3, according to the NF F31-119 standard [4]. The seats are composed in two parts: a structure made of the aluminium alloy AW 6060 T5 and a seat in composite material. The static test has been developed under load in y (transversal) direction to detect maximum displacement. The fatigue test has been developed under two normal load conditions with a frequency of 2 Hz.

Fig.3 Rolling stock's seats.

Static Testing

Four types of static tests have been carried out:

- T1: Mono-axial static test (figure 4) - P_{ymax} = 1 kN simultaneous on each seat, with load applied in load control by a ramp of 20 N/sec (total load applied by cylinder P_y = 4 kN);
- T2: Mono-axial static test (figure 5) - P_{ymax} = 1.2 kN, simultaneous on each seat, with load applied in load control by a ramp of 20 N/sec (total load applied by cylinder P_y = 4.8 kN);
- T3: Mono-axial static test (figure 6) - P_{ymax} = 1 kN, on one seat, with loads applied in load control by a ramp of 20 N/sec;
- T4: Mono-axial static test (figure 7) - P_{ymax} = 1.2 kN, on one seat, with load applied in load control by a ramp of 20 N/sec;

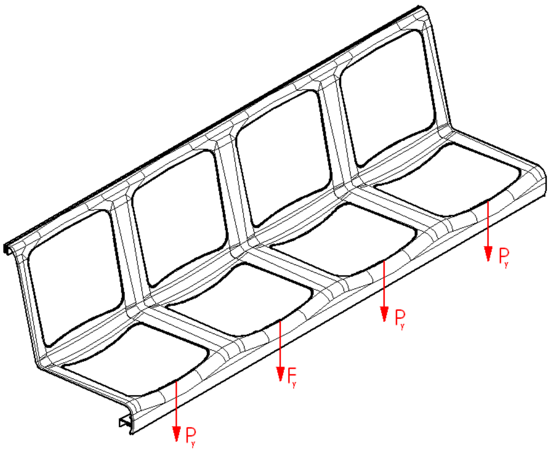


Fig.4 Mono-axial static load test configuration T1.

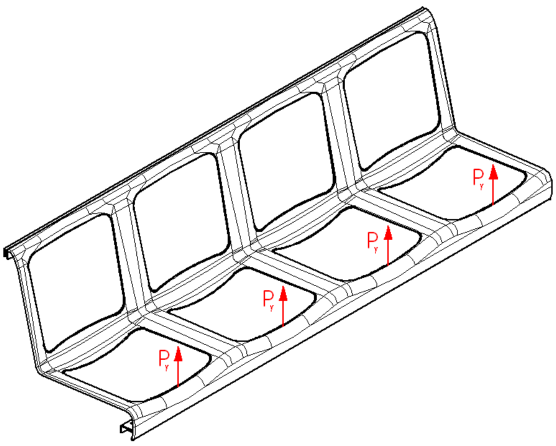


Fig.5 Mono-axial static load test configuration T2.

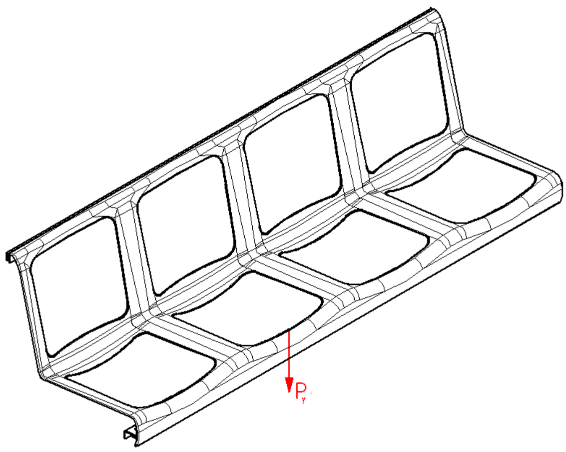


Fig.6 Mono-axial static load test configuration T3.

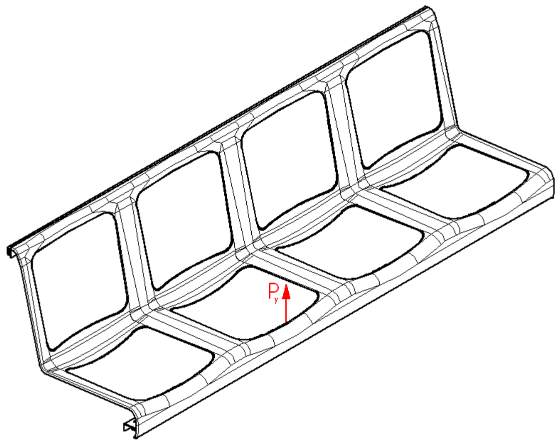


Fig.7 Mono-axial static load test configuration T4.

Fatigue Testing

A bi-axial fatigue test has been carried out: P_{ymax} = 1 kN simultaneous on each seat, with loads applied by a frequency of 2 Hz and ratio R = 0.01 (maximum total load applied by cylinder P_{ymax} = 4 kN) and P_{xmax} = 0.3 kN simultaneous on each seat, with loads applied by a frequency of 2 Hz and ratio R = -1 (total load applied by cylinder P_{xmax} = 1.2 kN). Figure 8 shows the loads configuration.

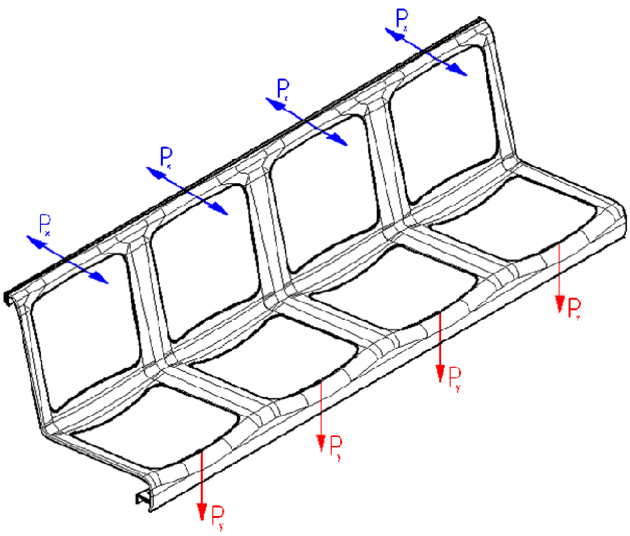


Fig. 8 Bi-axial fatigue loads test configuration.

FEM ANALYSIS

Stress and deformation fields developed on the structure during the tests are simulated using Finite Element Method (FEM). The numerical modeling was performed with the finite element code ANSYS. Figure 9 shows the mesh of the specimen figure 9; the model has 23951 nodes and 23305 SHELL elements with four o three nodes with 6 DOF's. For all load configurations a linear static analysis has been carried out. The structure made of aluminum alloy AW 6060 T5 has these properties: Young modulus E = 70 GPa, Poisson coefficient ν = 0.33. The composite material of seat, made by epoxy resin and chopped fiber, was modeled like isotropic material with these properties: E = 9.65 GPa, ν = 0.29.

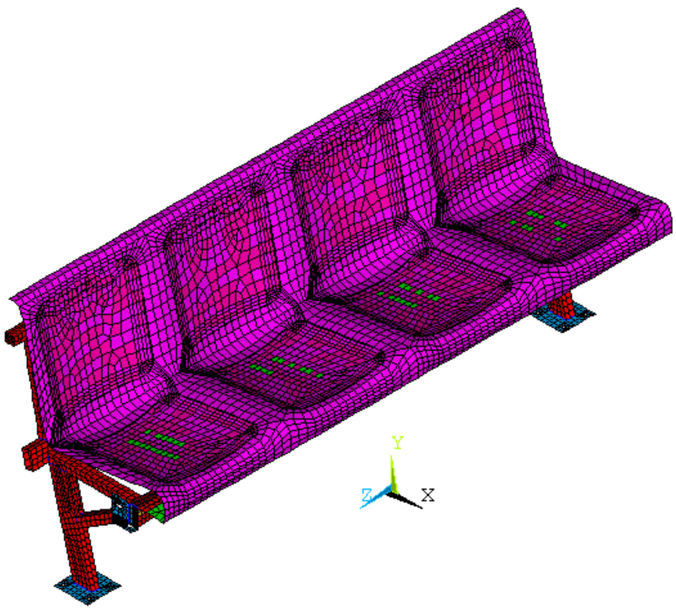


Fig. 9 FEM model of the rolling stock's seats.

RESULTS

Static Testing

The experimental results from the static tests are compared with FEM displacements and they are shown in Tables 1-4.

Comparing experimentally measured deflections with FEM predictions, the agreement is found to be acceptable; there are some differences between FEM and experimental results to lower load levels. It appears that a geometrical softening mechanism or a material non-linearity exists in the specimen, that has been not taken in to account by the FE-model, whereas a good correlation is seen at higher load level.

Table 1 Mono-axial static test results with loads configuration T1.

TOTAL LOAD APPLIED BY CYLINDER [N]	**u_y [mm] Seat N° 1**		**u_y [mm] Seat N° 2**		**u_y [mm] Seat N° 3**		**u_y [mm] Seat N° 4**	
	Exp.	FEM	Exp.	FEM	Exp.	FEM	Exp.	FEM
1000	0.65	0.87	0.99	1.06	0.97	1.06	0.63	0.87
2000	1.66	1.74	2.01	2.12	2.08	2.12	1.69	1.74
3000	2.69	2.61	3.26	3.18	3.24	3.18	2.68	2.61
4000	3.54	3.48	4.42	4.24	4.38	4.25	3.50	3.47

Table 2 Mono-axial static test results with loads configuration T2.

TOTAL LOAD APPLIED BY CYLINDER [N]	**u_y [mm] Seat N° 1**		**u_y [mm] Seat N° 2**		**u_y [mm] Seat N° 3**		**u_y [mm] Seat N° 4**	
	Exp.	FEM	Exp.	FEM	Exp.	FEM	Exp.	FEM
1200	0.99	1.25	1.51	1.79	1.51	1.79	1.02	1.25
2400	2.37	2.50	3.45	3.59	3.43	3.59	2.41	2.50
3600	3.78	3.76	5.46	5.38	5.42	5.38	3.79	3.76
4800	5.03	5.01	6.77	7.18	6.78	7.18	5.37	5.01

Table 3 Mono-axial static test results with loads configuration T3.

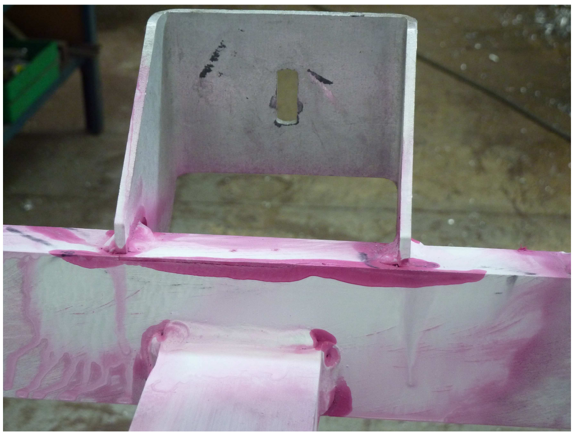
TOTAL LOAD APPLIED BY CYLINDER [N]	**u_y [mm] Seat N° 2** Exp.	FEM
250	0.40	0.59
500	1.01	1.18
750	2.01	1.78
1000	2.53	2.37

Table 4 Mono-axial static test results with loads configuration T4.

TOTAL LOAD APPLIED BY CYLINDER [N]	**u_y [mm] Seat N° 2** Exp.	FEM
300	0.65	0.71
600	1.34	1.42
900	2.29	2.13
1200	2.97	2.84

Fatigue Testing

A bi-axial fatigue test was performed; the following loads were applied: P_{ymax} = 1 kN simultaneous on each seat (total load applied by cylinder P_{ymax} = 4 kN); the loads were applied by a frequency of 2 Hz and ratio R = 0.01 and P_{xmax} = 0.3 kN simultaneous on each seat (total load applied by cylinder P_{xmax} = 1.2 kN), with loads applied by a frequency of 2 Hz and ratio R = -1. During the test the aluminum structure was inspected visually after intervals of 300,000 cycles. The fatigue testing was stopped at 1,200,000 cycles; in fact several cracks were found in the structure. Figures 10 and 11 show the cracks detected by liquid penetrant inspection (LPI).



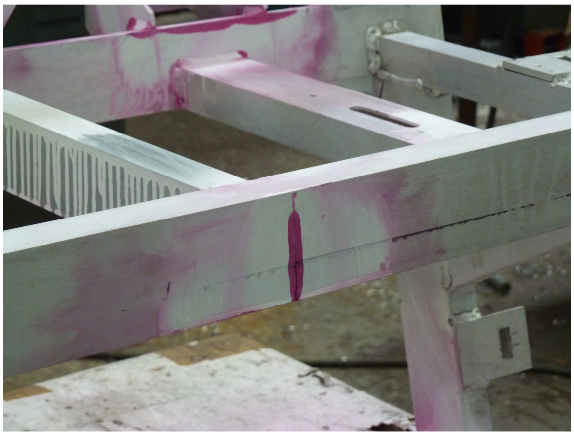


Fig. 10-11 Cracks detected by liquid penetrant inspection at 1,200,000 cycles.

CONCLUSION

A new machine for static and fatigue tests has been presented. It's able to test full scale specimens under two loading axes that are necessary to obtain a correct testing of the structural behaviour of rolling stock's seats. A localized loading system has been chosen to assure an established stress on the specimen and to induce independent deformations along different directions. A series of static and fatigue tests on full scale rolling stock's seats has

been carried out using the biaxial test machine. With reference to the static test, the correlation between numerical and experimental results is satisfactory.
The fatigue test was stopped at 1,200,000 cycles greater than 300,000 cycles expected in NF F31-119 standard, when several cracks was detected in some zones of the aluminum structure.

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