Alignment System of the Atlas muon spectrometer: Influence of humidity variations on dimensional stability of the bar system

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1. Introduction

The alignment system of the Atlas muon spectrometer is made of hollow composite bars whith dimensions of $80x80x4000$mm, figure [1]. It is necessary for the bar retain their specified dimensions even when exposed to variations in environmental conditions. This paper aims at analysing the dimensional stability of the bar system upon humidity variations in the environment.

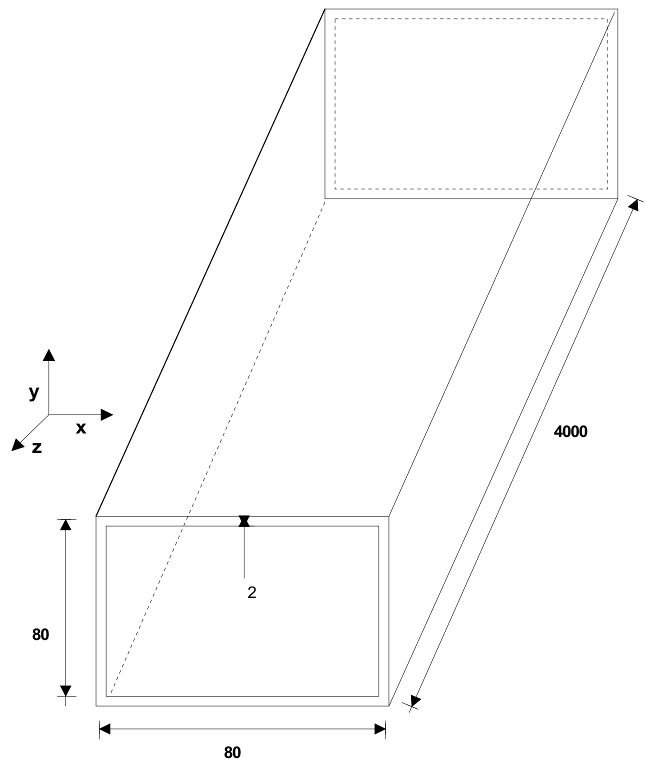

Figure 1: *Dimensions in mm of the muon spectrometer alignment tubes*

The material used is a carbon epoxy reinforced composites. Since the hygroelastic characteristics of the resin were not specified, the simulation considered a Hercule 3501-5 epoxy which gives a good average of the hygroelastic behaviour of epoxy resin. The pipes are supposed to be closed and only the lateral surface of the pipe is therefore in contact with the humid environment.

2. Unidirectional reinforced composites

First of all, the bars were considered to be made from unidirectional reinforced composite with fibers along the length of the tube.

2.1 Uniform relative humidity over time

The global response of the structure is analysed when the relative humidity of the environment increases suddenly from 0% to 50%. The variations in time of the hygroelastic deformations are represented in figure [2]. In this graph it can be noted that a "plateau" is asymptotically reached after 4 years. But the real frequency of the humidity variation in the tunnel is more important, so the structure remains unstable over time. The variations of the transverse deformation speed shown in figure [3] confirm these phenomena. Boundary conditions in terms of humidity are imposed only on the lateral surface of the pipes, and in this case the deformations change with the thickness of the tube. Therefore, at a given thickness, transverse and longitudinal deformations are constant along the whole length and the width of the tube, figure [3].

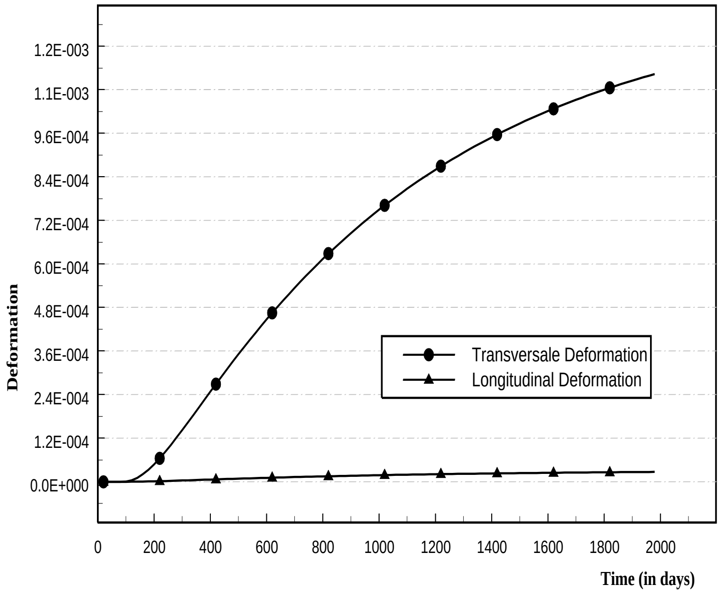

Figure 2: *Time dependence on the hygroelastic deformations -Carbon resin epoxy Hercule 3501-5, x/thickness=0.5,* $\Delta H = 50\%$.

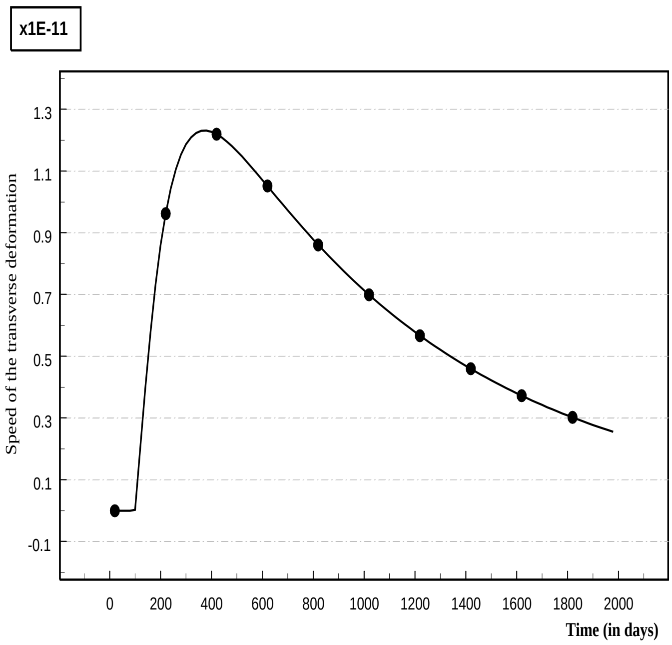

Figure 3: *Time dependence on the speed of the transverse deformation-Carbon resin epoxy Hercule 3501-5, x/thickness=0.5,* $\Delta H = 50\%$.

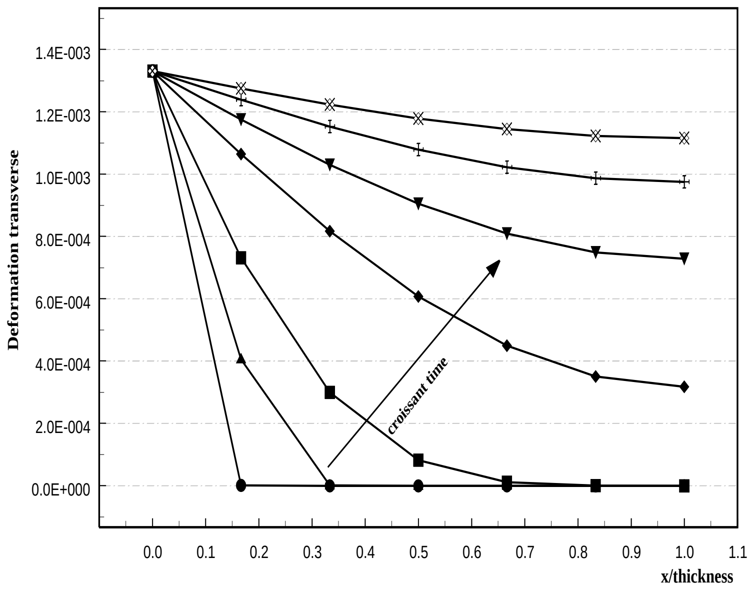

Figure 4: *Dependence on the thickness on the hygroelastic deformation, Carbon-Epoxy Hercule 3501-5,* $\Delta H = 50\%$.

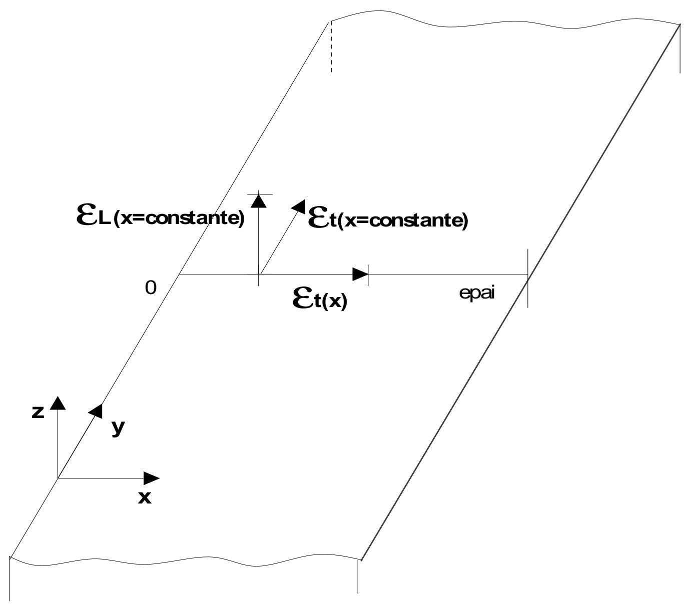

Figure 5: *Hygroelastic deformations*

In this case, displacements in the tube are given by the following relations :

$$\begin{cases} Uz & = \varepsilon_{long}(t) \cdot \text{length} \\ Uy & = \varepsilon_{tran}(t) \cdot \text{width} \\ Ux & = \int_0^e \varepsilon_{tran}(t)\, dx \end{cases} \tag{1}$$

where e is the thickness of the tube, ε_{tran} and ε_{long} respectively the transverse and longitudinal deformations, U_z, U_y et U_x the displacements. The displacements along the thickness, less than $3\mu m$ at the saturation point, are negligible in comparison with the other displacements of the order of

$100 \mu m$. Indeed, at the centre of the tube's thickness, for $x/e = 0.5$, displacements along the width and the length, shown in figure [6], are around $50 \mu m$ after one year. And near the lateral surfaces, figure [7] (where $x/e = 0.165$, near the external lateral surface), the displacements are greater, around $100 \mu m$, after the same length of time. So displacements along the thickness are being kept negligible in the following developments.

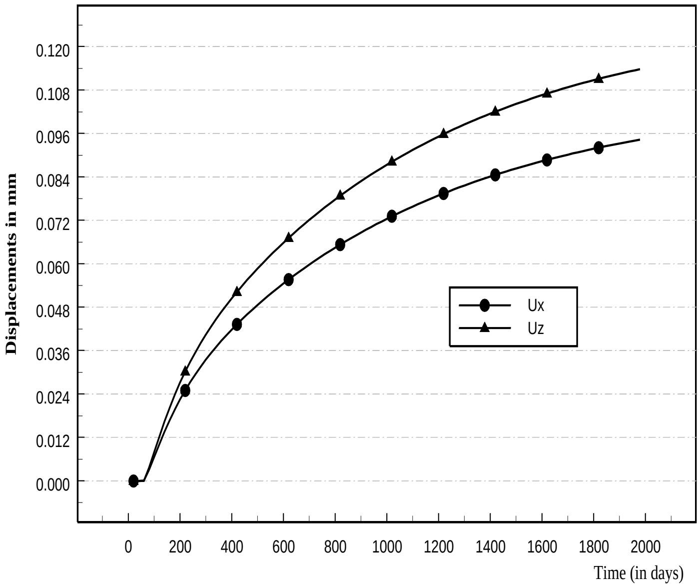

Figure 6: *Time dependence on the U_x and U_z displacements Carbon/Epoxy Hercule 3501-5, x/thickness=0.5* $\Delta H = 50\%$.

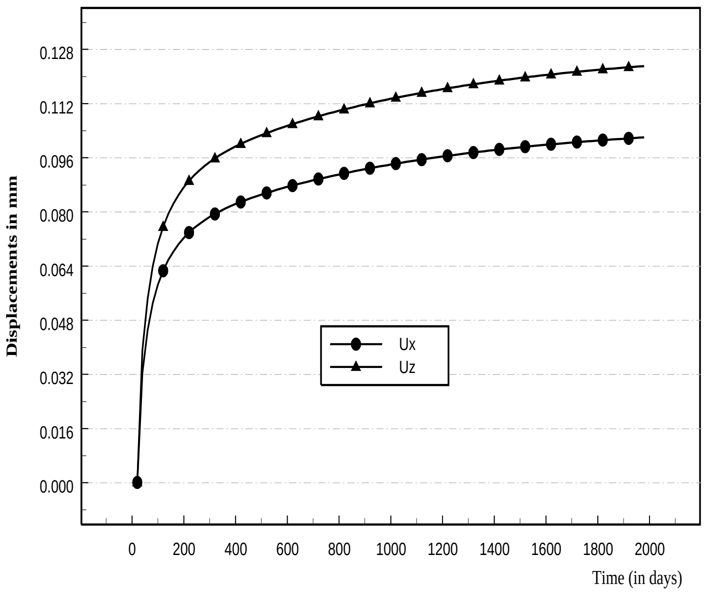

Figure 7: *Time dependence on the U_x and U_z displacements, Carbon/Epoxy Hercule 3501-5, x/thickness=0.165* $\Delta H = 50\%$.

2.2 Cycling load

Afterwards, the displacements obtained under cycling environmental conditions were analysed. To follow the environmental conditions of the ATLAS experiment the relative humidity was considered to be for one year with six months at 0% and the last six months at 100%. During the data taking period, the humidity will be controlled in the experiment aera at a maximum level of 60%, but during the maintenance period, the shaft will be opened and the humidity will change with external atmosphere. This means that the relative humidity in the experiment zone could increase to a level around 70% or decrease to around 10%. So in a first approximation a step of 50% could be considered.

In this study these assumptions were taken as a model for the humidity variations in the alignment system. But the real environmental conditions in terms of humidity of the muon chambers will have to be specified for a better prediction.

The global response of the pipes were analysed for a period of 4 years. As for the uniform boundaries conditions, the displacements are more important along the length and the width of the tube, and around $100\mu m$. It can be also noted that uniform composites allow the displacements along the fibres to be minimised in this case along the length of the tube, which is the preponderant dimension. But these kinds of composites are difficult to manipulate because of their weakness in the other directions.

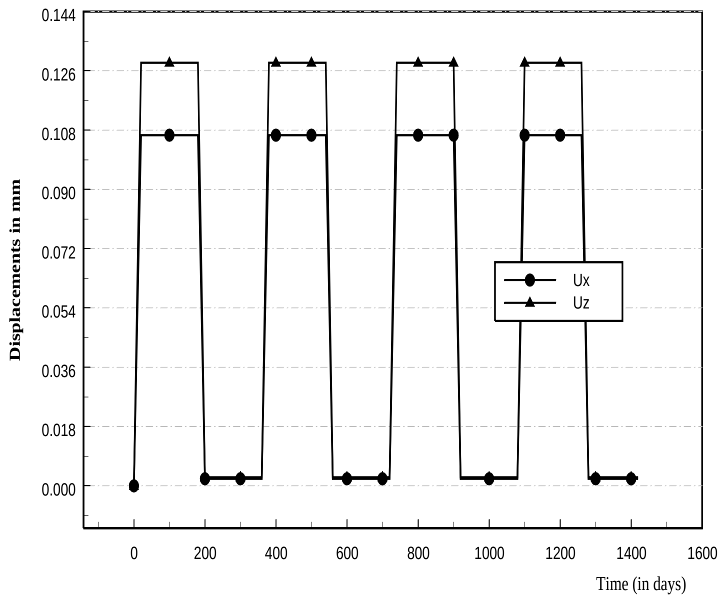

Figure 8: *Time dependence on the U_x and U_z displacements, Carbon/Epoxy Hercule 3501-5, x/thickness=0,* $\Delta H = 0\%$, *50%.*

3. Laminate composites

The case of laminate composite was also analysed. In this study symmetric laminates $(-15, 15, 0, 0)_{SE}$, $(-10, 10, 0, 0)_{SE}$ and $(17, 17, 17, 17)_{SE}$ were considered, where the thickness of the ply is 0.25mm. In both cases the preponderant displacements obtained followed the direction of the length of the tube. They are about $500\mu m$ for the $(17, 17, 17, 17)_{SE}$ laminate, $300\mu m$ for the $(-15, 15, 0, 0)_{SE}$ laminate and $200\mu m$ for the $(-10, 10, 0, 0)_{SE}$ laminate. The orientation of the fibres is therefore very important. The $(17, 17, 17, 17)_{SE}$ laminate, chosen for the alignment system, seems to be inappropriate because of the non-negligible humidity effects, and the weakness outside the direction of the fibres. By contrast, the $(-15, 15, 0, 0)_{SE}$ and $(-10, 10, 0, 0)_{SE}$ laminates have a better behavior not only along the length of the tubes, but also in the other directions.

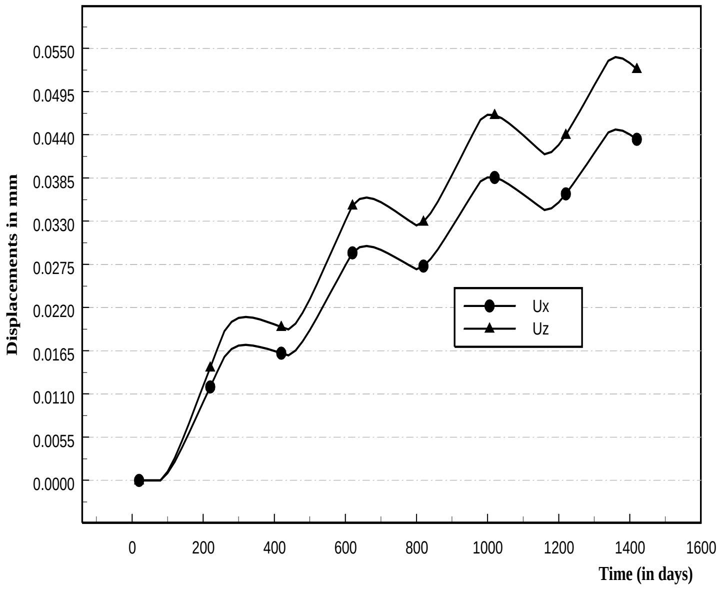

Figure 9: *Time dependence on the displacements in mm, Carbon/Epoxy Hercule 3501-5, x/thickness=0.5* $\Delta H = 0\%$, 50%.

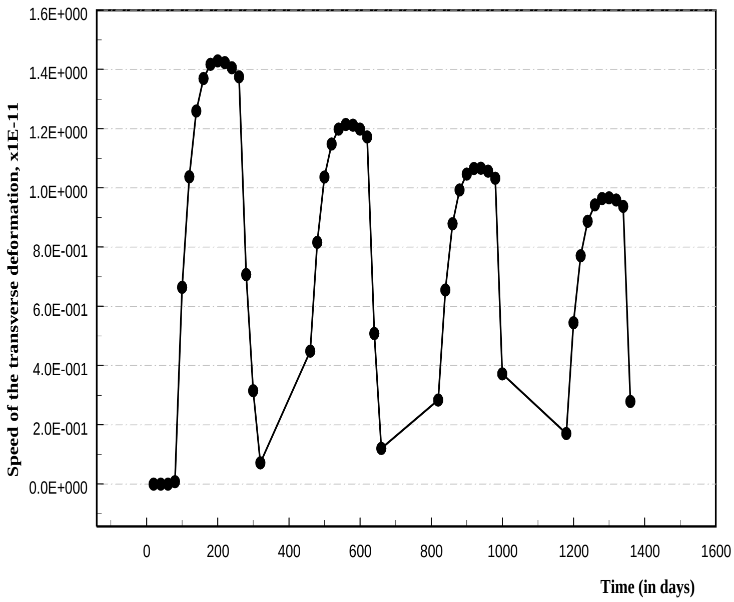

Figure 10: *Time dependence on the speed of the transverse deformation, Carbon/Epoxy Hercule 3501-5, x/épaisseur=0.5,* $\Delta H = 0\%$, 50%.

4. Conclusion

The moisture effect on the bar system of the ATLAS muon spectrometer is not negligible. These dimensional variations have to be taken into account in the alignment system. Specifically, the orientation of the fibres should be optimized. The conditions of the bar installation, use, storage and also the mechanical load should be analysed in order to get a better efficiency of the alignment system.

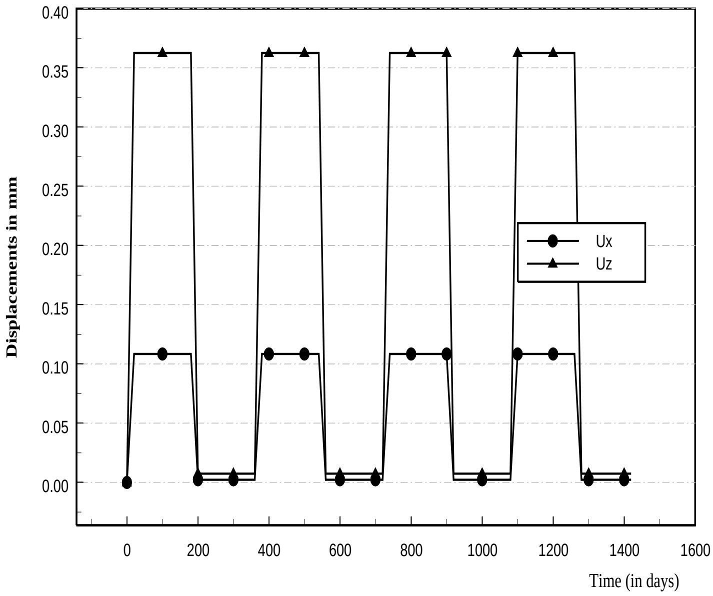

Figure 11: *Time dependence on the U_x and U_z displacements, Carbon-Epoxy Hercule 3501-5, x/thickness=0, $(-15, 15, 0, 0)_{SE}$ laminate, $\Delta H = 0\%$, 50%.*

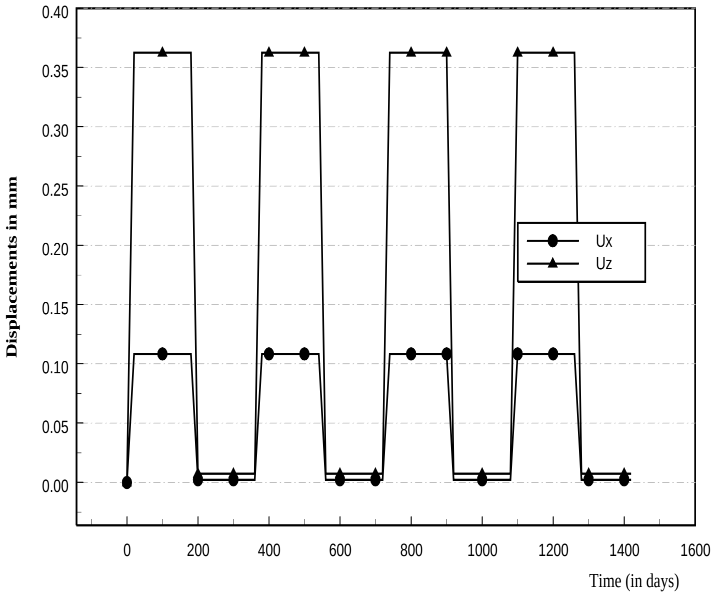

Figure 12: *Time dependence on the U_x and U_z displacements, Carbon-Epoxy Hercule 3501-5, x/thickness=0, $(-10, 10, 0, 0)_{SE}$ laminate, $\Delta H = 0\%$, 50%.*

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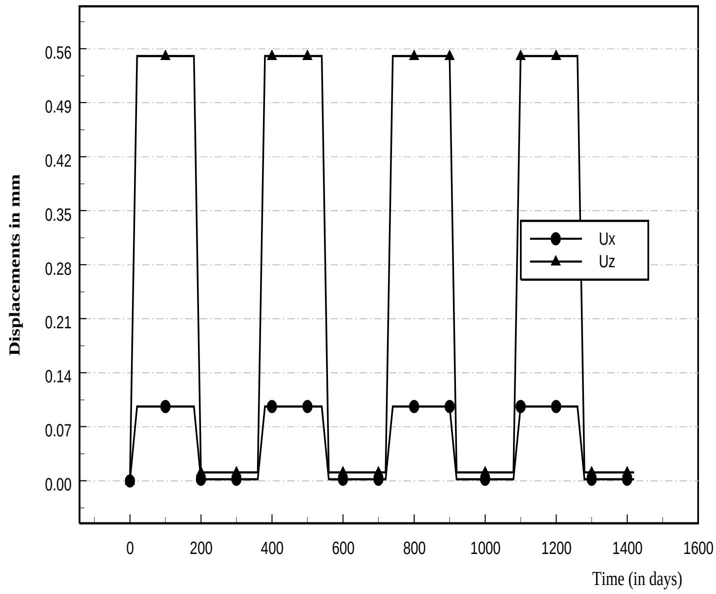

Figure 13: *Time dependence on the U_x and U_z displacements, Carbon-Epoxy Hercule 3501-5, x/thickness=0,* $(17, 17, 17, 17)_{SE}$ *laminate,* $\Delta H = 0\%$, *50%.*

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