ORIGINAL ARTICLE

THE EFFECT OF THE CONCENTRATED LOADING CREEP ON THE PROPERTIES OF THE STANDARD BEHAVIOR OF THE STABILITY OF LIGHT SANDWICH ELEMENTS WITH TWO METAL COVERING LAYERS AND A CORE OF POLYURETHANE (PUR)

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ABSTRACT

Background: Light sandwich panels with foam cores are increasingly using in engineering facilities, And Structural adaptation of these elements requires adequate knowledge of their behavior mechanism. Polyurethane PUR is one of the most used materials as filling in the locally produced sandwich panels with two covering layers of high- strength steel panels. We do not have scientific references that adopt certain specific structural calculation system to adjust the structural design standards by defining its modulus of elasticity on tension, compression, shear and adhesion related primarily to the quality and specifications of the product, either direct or long term loading to determine the maximum designed load of these panels. Creep phenomenon is one of the most important issues to assess the behavior of these elements; the scientific paper contains studying the influence of this phenomenon on the structural designing standards.

Keywords: *sandwich panel, creep, Polyurethane, shear modulus.*

1. INTRODUCTION

Producing and utilizing sandwich panels, that are formed of various materials simulating in their physical and mechanical properties her functional requirements as carried or insulated structural elements acoustically and thermally in the required engineering facilities, has globally and locally accelerated in the last decades.

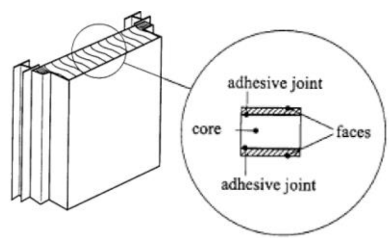
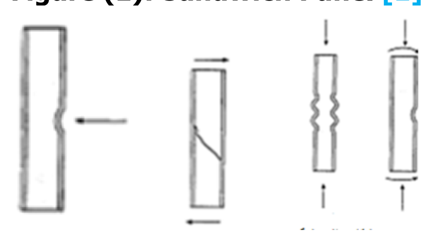


Figure (1): Sandwich Panel [1]

From these sandwich elements produced with the required lengths as ready elements, which widely used in civil engineering, and consisted of two metallic covering layers of a core of polyurethane, as cleared in figure (1), these light sandwich panels are increasingly employed as carrying walls and roofs in addition to their acoustic and thermal insulation, The pattern of collapse of these curvy sandwich elements vary between collapse by the waving wrinkling of the compressed covering layer due to the effect of vertical loads on the surface of the panel, as in figure (2a,2b), and the shearing collapse of the panel core according to the kind of effective loads, figure (2c), without excluding from these patterns the possibility of local distortion to some points



(d) (C) (b) (a)

Figure (2): Patterns of Collapsing sandwich panels [2]

and places of the influencing of loads on the sandwich panel, figure (2d)
patterns are experimentally revealed in: figure (3a,3b) for the waving wrinkling collapse, figure (3c) for the shearing collapse, and (3d) for the collapse by the buckling or the local distortion [2]

d: - a sample figure shows the local distortion happened when the collapse takes place with separation of the core's material.

c: shearing collapse of the core in a 45degree angle.

b: a sample figure explains rupture of the core and separation of the layer between the two points of applying load.

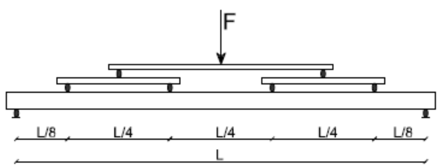
a: a sample figure explains the separation of the covering layer between the two points of applying load.

Figure 3: The figures presents the collapse patterns of the elements of curvy sandwich panels.

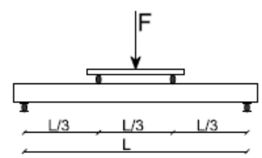
The importance of the research consists of tackling the experimental results for many of these sandwich panels with a core of polyurethane by the long term loading to get the standard data base of necessary mechanical and physical properties that regulate the standards of structural design of the structural elements which they made up of, and whose results can be exploited in the structural analysis that has the main product.

2. MATERIALS AND METHODS

Research methods have been based on the results of the experimental and analytical referential studies of the sandwich panels and elements which made of two covering layers and a core of polyurethane which produced in Syria , and setting out their loading transition diagonal or experimental standard stress-transition as one of the most important requirements of studying and designing with the influence of the direct loading, taking into account the creep influence that could be formed in these panels because of long-term loading on the derived designing standards, The next pictures represents the experimental structural system and the experiments of the samples as it is declared in figure (4)



B: a device model of quadruple concentrated loading samples



A: a device model of dual-concentrated loading samples

Figure 4: The experimental structural system of the tested slide and devices of loading samples

Beam transition in the sandwich panel consists of, as in the two previous figures, two transitions:
1_ bending transition predominately of the panel's two covering layers with neglecting their shearing transition influence that is next to zero according to the accuracy of results.

2_shearing transition predominately of the panel's core with neglecting its bending transition influence that is next to zero according to the accuracy of results.

Thus, for the panel's slide section given in the figure (5), the first loading system transitions equal [3, 4]:
Bending transition for the panel's two covering layers:

$$w_M = \frac{Fl}{72}(3l^2 - 4l^2/9) = \frac{23F\,l^3}{648D} \quad (1)$$

Where F the load of the total weight that applied on the test sample.

While the panel's core shearing transition is: $w_Q = \dfrac{1.2F\,l}{6G_c\,A}$ **(2)**

Therefor the relation between sample's transition and shear modulus is in the figure:

$$G_c = \frac{1.2F\,l}{6\,Aw_Q} \quad (3)$$

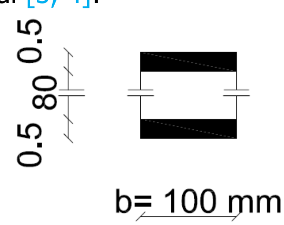


Figure 5: the sandwich panel slide's cross section

$I = btd^2/2 = 16200625 mm^4$

$A = bH = 100 \cdot 81 = 8100 mm^2$

where $w_Q = w - w_M$ for the tested samples, and w the measured transition of the sample at every stage

The compression stress on the covering layer's section is calculated after neglecting the role of the core in suffering such stress by the relation: $\sigma = \frac{F\,l}{6\,I}\frac{d}{2}$ **(4)**

Whereas the maximum shear stress in the core is calculated by the following relation: $\tau_c = \frac{F\,t}{2\,I}\frac{d}{2}$ **(5)**

Whereas for the panel's slide section that given in the figure(6), these transitions for the second loading system equal [3] [4]:

bending transition of the panel's two plates: $w_M = \frac{F\,l}{192D}(3l^2 - 28l^2/64) = \frac{41F\,l^3}{3072D}$ **(6)**

Where F the load of the total weight that applied on the test sample.

While the panel's core shear transition is: $w_Q = \frac{1.2\,F\,l}{8G_c\,A}$ **(7)**

Therefor the relation between sample's transition and core shear modulus is:

$$G_c = \frac{1.2\,F\,l}{8\,A w_Q} \quad \textbf{(8)}$$

Where $w_Q = w - w_M$ for the tested samples and w measured transition of the sample at every loading stage.

While the compression stress of the covering layer's plate:

$$\sigma = \frac{q l^2}{8\,I}\frac{d}{2} = \frac{F\,l}{8\,I}\frac{d}{2} \quad \textbf{(9)}$$

The maximum shear stress in the core is calculated as: $\tau_c = \frac{F\,t}{2\,I}\frac{d}{2}$ **(10)**

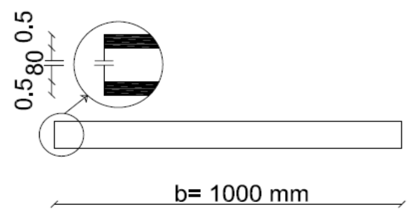


Figure 6: the cross section **of sandwich panel slide**

$I = btd^2/2 = 1620062.5mm^4$

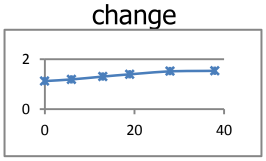
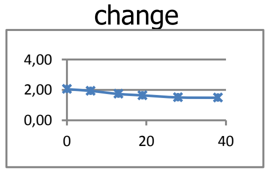
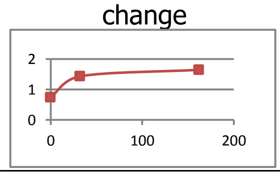
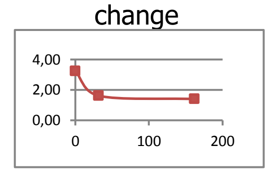
$A = bH = 1000 \cdot 81 = 81000mm^2$

To attain the wanted purpose of this scientific paper, the needed tests by both devices have been done on slides of the samples in dimensions (81 x 100 x1000)mm, and others in dimensions (81 x1000 x2000)mm by loading them via filling the loading basin with the needed strength in order to be concentrated in their right places according to testing system, and to make their influence persist for a long time on the panel, and all of that is compatible with the recording of transitions' measures happened in the sample through different testing stages.

3. RESULTS AND DISCUSSION

Firstly: models of sliced samples 81 x100 x 1000 mm

Table 1: Results of testing creep for samples 1,2 (duration of test 38 days for the first, and 162 days for the second).

State of loading		Concentrated in two points								
Sample number		1						2		
Duration of loading (day)		0	6	13	19	28	38	0	32	162
Applied stress MPa	σ	37.17	37.17	37.17	37.17	37.17	37.17	36.56	36.56	36.56
	τ	0.056	0.056	0.056	0.056	0.056	0.056	0.055	0.055	0.055
δ_i/l x 10^{-2}		1.122	1.189	1.303	1.393	1.51	1.531	0.735	1.429	1.643
Shear modulus G_c		2.04	1.93	1.73	1.63	1.5	1.48	3.23	1.61	1.39
Temporal chart of $10^2 \times \delta_i/l$ change 		Temporal chart of G_c change 			Temporal chart of $10^2 \times \delta_i/l$ change 			Temporal chart of G_c change 		
Sample 1					Sample 2					
Definitions		δ_0 - shifting the middle of sample when completing its loading at zero time of starting the								

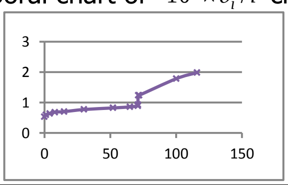
	current distortion, δ_i - shifting the whole sample until the day *I*, t_i - time per days until the day *I*, l - *length of sample's span*
Notes	sample 1:sample 1 had loaded on day thirty eight until it collapsed, so the collapse stresses achieved the values: $\sigma_{cr} = 66.06 MPa$, $\tau = 0.099 MPa$ the value of total δ / l of the sample's transition at the collapse moment exceeded the value 2.14% . The last stages of the continuity of loading sample 2 accompanied by a big local distortion below the point of load concentration.

Secondly: models of sliced samples 81x1000x2000mm:

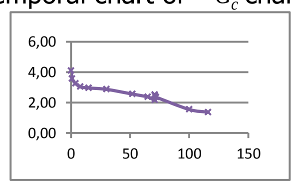
Table 2: Testing results of sample 1 creep (duration of test 116 days)

State of loading		Concentrated in four points ,and the panel's testing direction is longitudinal												
Sample number		1												
Duration of loading (day)		0	1	4	8	15	30	52	65	71	71	72	100	116
Applied stress *MPa*	σ	54.3	54.3	54.3	54.3	54.3	54.3	54.3	54.3	54.3	81.7	81.7	81.7	81.7
	τ	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.082	0.082	0.082	0.082
δ_i / l x 10^2		0.534	0.593	0.637	0.685	0.703	0.771	0.822	0.856	0.890	1.237	1.240	1.781	1.987
Shear modulus G_c		4.08	3.56	3.24	2.96	2.87	2.56	2.37	2.25	2.15	2.53	2.36	1.55	1.37

Temporal chart of $10^2 \times \delta_i / l$ change



Temporal chart of G_c change

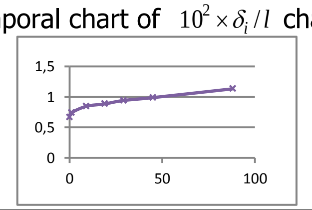


notes	Sample 1 had tested in three phases where the first phase stress achieved $\sigma = 54 MPa$ and it lasted for 71 days, the stress was increased in the second phase to almost 82 MPa , and its influence lasted for 45 days, then it was loaded after that in the third phase until it collapsed with the stress $\sigma_{cr} = 95.26 MPa$. We conclude from these charts that the daily increasing rate of transitions decreases due to the stress 69.2 MPa quickly through the first days of, and we note that its ratio during the first days increases almost 10 times more than its increasing ratio for the period between 65-71 days before removing the stress from the sample .

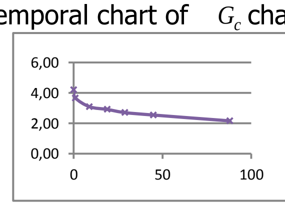
Table 3: Testing results of sample 2 creep (duration of test 88 days)

State of loading		Concentrated in four points ,and the panel's testing direction is longitudinal						
Sample number		2						
Duration of loading (day)		0	1	9	19	29	45	88
Applied stress *MPa*	σ	69.2	69.2	69.2	69.2	69.2	69.2	69.2
	τ	0.069	0.069	0.069	0.069	0.069	0.069	0.069
δ_i / l %		0.666	0.738	0.844	0.885	0.940	0.989	1.132
Shear modulus G_c		4.20	3.66	3.08	2.91	2.70	2.54	2.16

Temporal chart of $10^2 \times \delta_i / l$ change



Temporal chart of G_c change

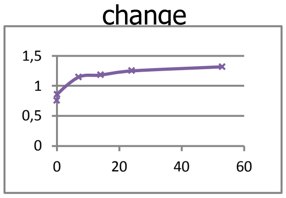


notes	We conclude from these charts that the daily increasing rate of transitions decreases due to the stress 69.2 MPa quickly through the first days of loading beginning , and we note that its ratio increases almost 22 times more than its increasing ratio for the period between 45- 88 days .

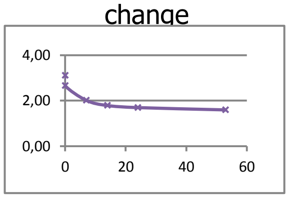
Table 2 and 3: Results of creep test for samples 3, and 4 (duration of test 53 days for the first and 235 days for the second).

State of loading		Concentrated in four points ,and the panel's testing direction is longitudinal												
Sample number		3					4							
Duration of loading (day)		0	7	14	24	53	0	7	14	24	53	67	105	235
Applied stress MPa	σ	62.11	62.11	62.11	62.11	62.11	62.11	62.11	62.11	62.11	62.11	62.11	62.11	62.11
	τ	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062
δ_i / l %		0.754	1.145	1.180	1.248	1.317	0.811	1.134	1.158	1.211	1.281	1.288	1.303	1.349
Shear modulus G_c		3.11	2.01	1.81	1.70	1.60	2.58	1.84	1.73	1.64	1.54	1.53	1.51	1.48

Temporal chart of $10^2 \times \delta_i / l$ change

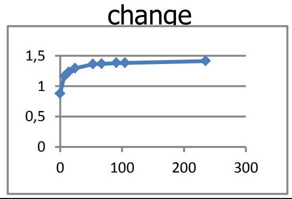


Temporal chart of G_c change

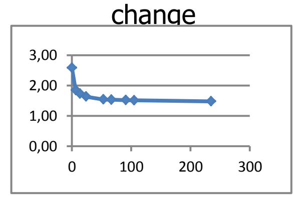


Sample 3

Temporal chart of $10^2 \times \delta_i / l$ change



Temporal chart of G_c change



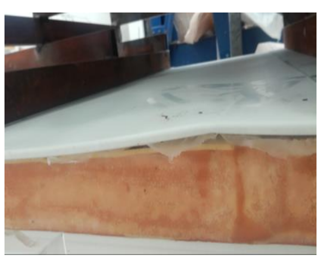
Sample 4

notes	The results contained in this table are creep test results of the sample (3) (item 1/8) by loading it on its second face after it was tested by the weekly periodic loading on its first face for six consecutive loading terms. The results contained in this table are creep test results of the sample (3) (item 2/8) by loading it on its second face after it was tested by the weekly periodic loading on its first face for three consecutive loading terms. The pace of decline of the daily increasing rate of transitions through the first days of loading for the above samples also applies on these two samples , we conclude that its ratio through the first seven days increases to almost 22 times more than its increasing ratio through the period between 24-53 days.

Too many or few scattered experimentation results of mechanical behavior of the material aren't perceived as credible in the structural analysis operation of designing the structural elements, but that will happen based upon derived physical and mechanical properties of the material from which the element made up of, by returning scattered behavior of tested samples to a united standard mechanical behavior, often linear, within a specific loading field to attain terms of the design and analysis of the elastic theory sufficiently, taking into account the technique of material production, and its loading and testing conditions.

Standard return factors of shearing bend experiments of sandwich panels primarily consist of two basics:

1- the relation between the applied loads and their accompanied transitions, 2- elastic shearing modulus of core material changed with the strength of the load applied on the panel, and the time of its influence.



The pattern of the happened collapse

Figure 7: the figure showed the collapse of one of the samples during the experiment.

Continuity of the panel's working stability and the permanence of creep in it closely relate to strength of stresses applied on it, as we noticed the sample that was submitted to increasing in stresses strength, after its first creep with a stress approximates 54 MPA for 71 days, to reach approximately 82MPA, and almost to arrive by that to the biggest value between tested samples stresses with the two slides models is the sample 1.

All these and other results recorded in the tables of the tested samples of the two models mentioned in this scientific paper had been tackled mathematically to deduce the formula of the optimal collecting mathematical function to describe the behavior of creep of the elements composed of such sandwich panels, which are the object of this research and others, according to diagonals patterns of the temporal variables mentioned in these tables, thereby we reached the following mathematical relation from which we can calculate the transitions of sandwich panels, whether for concentrated direct loading or continued effective one : $w(t)=e^{0.165\sqrt{20Ln(t+1)+a}}\frac{\sigma_i}{56}+\frac{5\cdot 10^6 F}{48D}(\frac{l^3}{8\cdot 10^6}-\frac{l}{2})$ **(11)**

As we notice here, this relation represents exponential function of the logarithmic function which is dependent to the time of continuity of loading influence (t) by days, taking into consideration the strength of applied stress and the affected load on the plate slide.

Where in this relation:

σ_i :Tthe stress applied on the plate slide, unit MPa,
F : Load result affected the slide, unit N,
l : Length of plate slide, unit mm,
$D=E_f I$: bending stiffness of the two covering layers of plate slide, unit N.mm2

Whereas the value of the constant a under the root in this function, we deduced that it equals 250 for the basic product of the research, while we expect its value ranges between 240-260 for any other product according to its components' quality, as this constant is the lonely variable in this relation for any product of such sandwich panels products.
We deduce from subtracting the formula of the relation (6) of the quadruple concentrated loading model from the two sides of the relation (11), and making the correction to it by the formula $w_Q(t)=w(t)-w_M$, after neglecting the influence of the term $\frac{F\,l}{3072D}$, due to smallness of its influence on the results:

$w_Q(t)=e^{0.165\sqrt{20Ln(t+1)+a}}\frac{\sigma_i}{56}-\frac{5\cdot 10^6 F}{48D}\frac{l}{2}$ **(12)** $w_Q(0)=e^{0.165\sqrt{a}}\frac{\sigma_i}{56}-\frac{5\cdot 10^6 F}{48D}\frac{l}{2}$ **(13)**

Thus, we find by entrance both of these formulas (12) and (13) to the equation (8): $G_c(t)=\frac{1.2\,F\,l}{8\;A\,w_Q(t)}$ **(14)**

Whereas subtracting the relation (1) of the dual concentrated loading model from the two sides of the relation (11), and correction lead to : $w_Q(t)=e^{0.165\sqrt{20Ln(t+1)+a}}\frac{\sigma_i}{56}-\frac{5\cdot 10^6 F}{48D}\frac{l}{2}-\frac{Fl^3}{108D}$ **(15)**

Thereby the shear modulus of this case according to the equation (3) is: $G_c(t)=\frac{1.2\,F\,l}{6\;A\,w_Q(t)}$ **(16)**

The important thing, which should be indicated to, is that calculating the transitions and the moduli accompanied the direct loading could be done directly for any other models by using these research relations, as we noticed through the tackled example above, after determining the value of the constant (a) in these relations, which could be deduced by doing a couple of simple tests to determine some of the mechanical and physical properties of the studied model by the transitions happened in these tests.

For taking an overview on calculation with the derived research and experimental referential relations $\phi_t=0.12t^{0.36}$ [5], we showed in the figure (8) the graphic representation of calculation results by these two relations for a period of time up to 2000 days, and comparing them with the diagonal of the average of experimental results of the two slides 3, 4, as the figure (8) shows.
As noted from the figure (8) that the values in the two relations converge in the first days in the field 150-300 days whereas the more the loading time advances the bigger the variation between them will be.

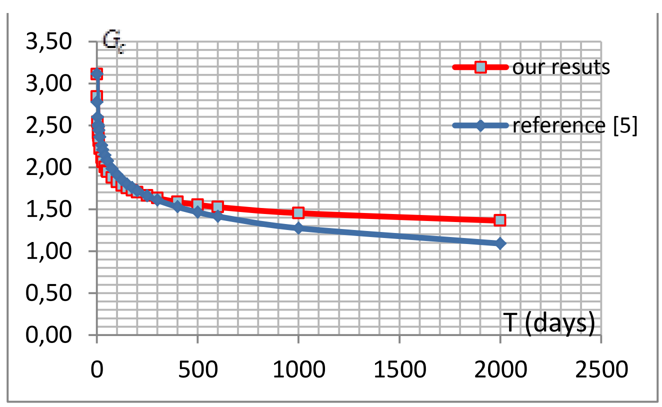


Figure 8: the figure showed the two diagonals of the shear modulus by the research and referential relation.

4. CONCLUSIONS

1- The biggest ratios of concentrated loading creep form in the first hours, consequently the first days of continuity of loading especially the first day, as this ratio can reach in the first hour of loading to 20% of the creep that happened in the first day, while reach in the first day to more than 20% of the ratio of creep happened after 50 days, or more than 12% of what happened for about 100 days.

2- The calculation of the creep modulus is done according to the referential formulas of any panels by the density $\rho \geq 40kg/m^3$ with just the temporal experimental relation $\phi_t = 0.12\,t^{0.36}$ Without taking into account other effects or any engineering or mechanical properties of the panel slice components especially the moduli of elasticity and the panel thickness.

3- The panel slide transitions, which are loaded with concentrated loads, should be calculated referentially starting from the relation of the experimentally specific creep modulus to the shearing modulus of elasticity to the permanent direct loading, whilst, by the research relation (6) and its results of formulas and relations, we can calculate the shearing and total transitions and the shearing moduli accompanied to the temporal and direct loading, as noted in the resolved example, where each value of these parameters represents an exponential function of an logarithmic function of time function, as long as the density of the panel core is $\rho \geq 40kg/m^3$

4- we recommend more research on the creep of such panels for longer duration than continuing of loading of the panel by observing the variables every day for at least more than 500 days to register the results that had been reached to in this paper more.

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