Experimental investigation and FEA of AlMg3-stiffened rectangular plate subjected to concentrated load

Mohammed Midhat Hasan[1] **Mazin Yaseen Abbood[2]**

Abstract

In this paper, AlMg3-plates are studied through experimental and numerical using finite element representation under concentrated load at the center point. The plates of (300- × 200 mm) are clamped at the shorter ends and strengthened longitudinally by one rib at the centerline and two at different spans. the stiffened plates were modeled using a 3-D 10-node tetrahedral element with a non dimensional analysis. The models were validated using the results of tests on full-size stiffened plate specimens and were subsequently used to perform the study of the parameters presented in this paper. The parameters investigated are: the maximum stress, deflection of the plate and the position of ribs. Effect of the investigated parameters on the concentrated load strength were studied within elastic range. FEA give closer results with those of experimental and these results show that the use of two parallel ribs with a 40-mm span improves the strength of the plate. Due to these results, further investigation is presented to show the optimum thickness of the ribs at the best span.

Keywords: Experimental, FEA, AlMg3-plate, concentrated load, stiffener.

دراسة عملية وتحليل باستخدام العناصر المحددة لصفائح AlMg3 مستطيلة ومقواة ومعرضة إلى حمل مركز

مازن ياسين عبود **محمد مدحت حسن**

الخلاصة:

في هذا البحث، تمت دراسة تأثير حمل مركز في وسط صفائح صفائح الألمنيوم – مغنيسيوم (AlMg3) عمليا وعددياً من خلال استخدام طريقة العناصر المحددة. ثبتت هذه الصفائح ذات الأبعاد (٣٠٠ ملم × ٢٠٠ ملم) من الحافات القصيرة وتم تقويتها طولياً باستخدام ضلع واحد في خط المنتصف و ضلعين بمسافات بينية مختلفة. كمقارنة، في الجزء الثاني، مثلت الصفائح المقواة باستخدام العنصر ثلاثي الأبعاد ذو العشر عقد الرباعي السطوح مع تحليل لا بعدي. تم إثبات النماذج باستخدام نتائج الاختبارات على الحجم الكامل لعينات الصفائح المقواة ومن ثم استخدامها لانجاز المتغيرات المقدمة في هذا البحث.

المتغيرات المدروسة هي: الإجهاد والانفعال الأعظم للصفائح وموقع أضلاع التقوية. تم دراسة تـأثير المتغيرات المحققة على الحمل المركز ضمن حدود المرونة. التحليل باستخدام العناصر المحددة أعطى نتائج مقاربة جداً للنتائج العملية، وهذه النتائج أظهرت أن استخدام ضلعي تقوية متوازيين وبمسافة بينية مقـدارها ٤٠ ملم. يحسن من مقاومة الصفيحة، اعتمادا على هذه النتائج، قدمت دراسة إضافية لبيان الـسمك الأمثـل لأضلاع التقوية عند أفضل مسافة بينية.

[1] M.Sc. Applied Mechanics Teacher Dept. of Production Eng. & Metallurgy University of Technology

[2] M.Sc. Applied Mechanics Asst. Teacher Dept. of Mechanical Engineering University of Anbar

1. Introduction

For a given loading, the stiffness of a plate or shell structure can be increased significantly by the addition of ribs or stiffeners. Previously, the optimization techniques are mainly on the sizing of the ribs. The more important issue of identifying the optimum location of the ribs has received little attention. Thin aluminum plates that are stabilized in one direction by stiffeners are used extensively in the structures in which a high strength-to-weight ratio is important. More than 7000 series wrought aluminum alloys are used for aerospace applications because of their combination of high strength, stress-corrosion-cracking resistance, and toughness [1]. Being economical and strong enough, stiffened plates are widely used in all kinds of circumstances, such as bridges, ship hulls or decks, and aircraft structures. Numerous studies have analyzed stiffened plates. Earlier researchers simulated stiffened plates with orthotropic models [2] or grillage models [3]. However, these models did not achieve satisfying results in solving generalized stiffened plate problems. Hence, subsequent researchers tended to regard the plate and the stiffener separately and then combine them by imposing the displacement compatible conditions between the plate and the stiffener. Several methods have been developed, such as the Rayleigh–Ritz method [4–7], the finite element method (FEM) [8–10], and the constraint method based on finite elements [11]. Of all these methods, finite element methods are the most convenient and can be used in large, complex structures due to the advances in computing that have made the methods extensively used in industry. As an alternative to FEMs, the element-free method [12], mesh-free or meshless methods [13–16] have recently been made popular in engineering analysis. Unlike the meshing process in the FEM, the mesh-free methods only discretize the domain of a problem to a set of scattered points. The mesh-free methods are flexible in many instances, such as moving boundary problem, crack growth with arbitrary and complex paths, and phase transformation problems. In such cases, FEMs can encounter difficulties in dealing with discontinuities that do not coincide with the original mesh lines. It is obvious that re-meshing will be needed in each step of the solution procedures, which will be quite involved. Mesh-free methods construct the approximation solution of a problem entirely in terms of a set of nodes that are distributed in the problem domain, and no elements or any other interrelationship among the nodes are needed. Without the need for meshes, the meshless methods avoid the disadvantages of FEMs. By Lam and Santhikumar [17], a methodology has been developed for the automatic determination of the optimum locations of the ribs for a given set of design constraints.

Graciano and Johansson [18] present a design procedure for the determination of the ultimate resistance of longitudinally stiffened girder webs to concentrated loads. The influence from the longitudinal stiffener is considered in the slenderness parameter, through the buckling coefficient. This procedure is harmonized with other design procedures currently used for describing buckling problems in steel structures. An expression is developed for the buckling coefficient based on finite element analysis. The interaction between the web plate with flanges and a longitudinal stiffener was considered in the analysis. The ultimate strength according to the design procedure presented and the results are compared with available experimental results. Also they investigated the interaction with bending.

Peng et. al. [19] present an element-free Galerkin (EFG) method for the static analysis of concentrically and eccentrically stiffened plates based on first-order shear deformable theory (FSDT). The stiffened plates were regarded as composite structures of plates and beams. Their results show good agreement with the existing analytical and finite element solutions.

Virág [20] investigated the minimum cost design of longitudinally stiffened plates using the strength calculation methods. Deflections due to lateral pressure, compression stress and shrinkage of longitudinal welds are taken into account in the stress constraint. The self-weight is added to the

lateral pressure. The local buckling constraint of the base plate strips is formulated as well.

Radovi! et. al. [21] studied the Recrystallization behaviour of AlMg3, AlMg4.5Mn and AlMg6Mn alloy plates subjected to different thermomechanical treatments (TMTs), by means of optical microscopy and hardness measurements.

Three-dimensional finite element analyses are used by Moreira et. al. [22] to calibrate the stress intensity factor in a cracked stiffened plate subjected to remote uniform traction. An accurate numerical determination of the stress field and stress intensity variation through the thickness of a central cracked plate was first carried out in order to evaluate three-dimensional effects. A stiffened cracked plate was then analyzed, taking into account the results and the conclusions obtained in the previous study. Such a structure was chosen due to the growing interest for large integral metallic structures for aircraft applications, following the continuous need for low cost and the emergence of new technologies. The J-Integral technique was used to calculate the values of the stress intensity factor along the plate thickness. The plane strain behavior near the crack front and the variation of the opening stress are discussed.

Based on the higher-order global–local theories, a finite element model is proposed by Li Li and Ren Xiaohui [23] to study the bending behavior of stiffened laminated plates. The proposed model treats the embedded stiffeners as the part of laminated plate, so that the compatibility of displacements and stresses between the plate and the stiffeners can be automatically satisfied. Distributions of the displacements and stresses through the thickness of laminates were also given for the first time, which can serve as references for future investigations as such information is lacking in the published literature. In addition, the impact of the stiffeners on the bending response of the stiffened laminated plates is also studied in terms of the quantity, the collocation and the geometry of stiffeners. Numerical results showed that the higher-order global– local theories are more suitable for predicting the bending response of thick and moderately thick stiffened laminated plates compared to the first order theory commonly used in engineering. By varying the quantity, the collocation and the geometry of stiffeners, the stiffness and the strength of stiffened laminated plates can be remarkably improved.

2. Experimental Work:

The test rig and the test specimen's plates are shown in figure (1) shows. The plates are (300- × 200-mm) and are made of AlMg3 (3.1 Mg, 0.03 Mn, 0.31 Fe, 0.09 Si). Thickness of the flat one (unstiffened) are 2-mm. The other plates (stiffened) are machined – at the Shaheed Company – from 4mm-thick plates to get equal thickness, 2-mm, for plates and stiffeners. First, one longitudinal stiffener is used at the centerline of the plate. Other models are stiffened by two parallel ribs with span, w, equal to 40, 80, and 18 mm as shown in figure (2). After machining, two-stage annealing was applied – at the Labs of Mechanical Engineering Dept, University of Anbar – in order to develop as much as possible homogenous microstructure of the tested plats. During the first step of annealing simulating homogenization, the dissolution of the intermetalic particles at 565°C takes place as it was found in previous papers [24]. During subsequent annealing at 450°C precipitation and particle coarsening should take place, leading to increased mobility of grain boundaries and the development of a rather homogenous grain structure [25].

Load is concentrated at the mid point of each tested plate and increased gradually from zero to the maximum (within elastic limit). Finally, the Baty dial-gauge (see Fig.1&2) is used to measure the deformation of the models.

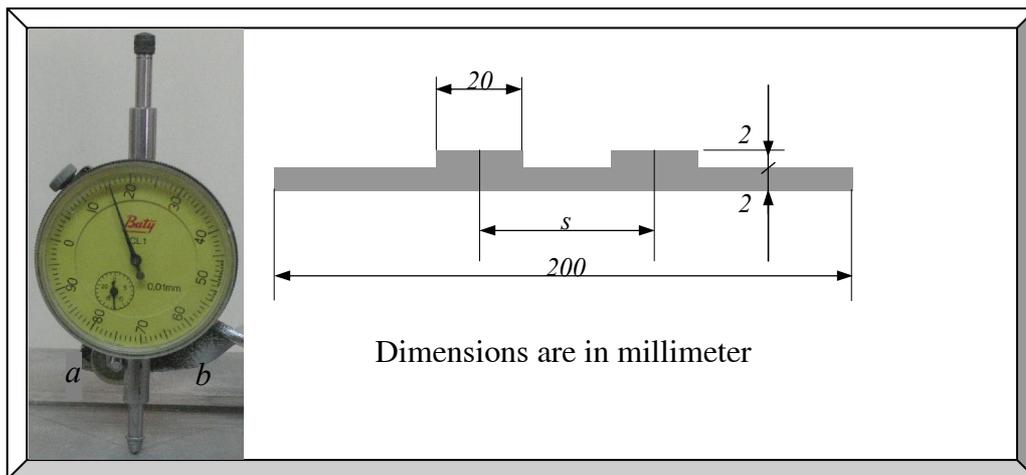**Figure (1) The constructed test rig and the test specimen's plates**

Dimensions are in millimeter

Figure (2) a- The Baty dial-gauge used b- A view of the plate stiffened with two parallel ribs (s = 40, 80 and 180 mm)

3. Numerical Analysis

The numerical analysis was done using Finite Element technique. The models used in the experimental part are simulated using the finite element software, ANSYS11. The plates are clamped at the shorter ends and meshed with a 3-D 10-node tetrahedral element. At the center of the model, load is concentrated then nonlinear with large displacement analysis is used to solve each case. Figure (3) shows contour plots of the total displacement (left column, d1– d5) and of the Mises stress distribution (right column, S1– S5) for all models under maximum load.

4. Result And Discussion:

Figure (4) shows the results obtained from both experimental and FE investigations. First, in the flat plate, maximum displacement are measured experimentally and is found to be vary from zero (no load) to 1.12 mm. Numerically, maximum displacement are vary from zero to 1.107 mm. with maximum von-Mises stress up to 56.3 MPa. When the plat is stiffened with one longitudinal rib at the center line, case (1), maximum displacement is decreased and the stress is increased with 5.33 percent; so no doubt it is an unpractical case. Similarly cases   (3 & 4) are also unpractical due to the augment in stresses. The use of two parallel ribs at a span of 40-mm, case (2), is the best to strengthen the plate. In this case, the displacement is decreased and the maximum stress is reduced with 38.54 percent as shown in the final graph of figure (4). This would guide us to study the strengthening of the plate with two parallel ribs at a small span in detail.
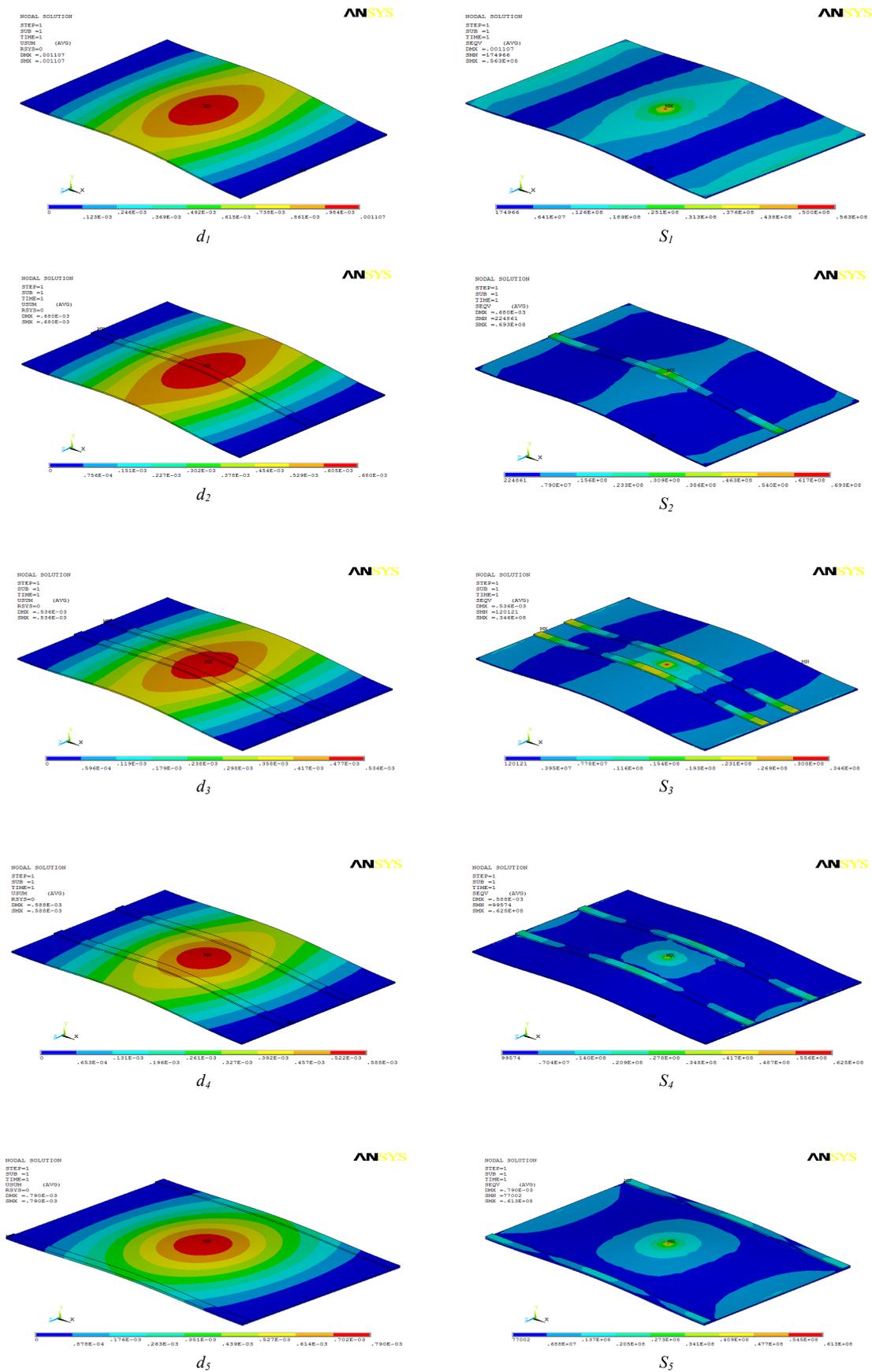
Figure (3) Contour plots of the total displacement (left column, d1– d5) and of the stress distribution (right column, S1– S5) for all models under maximum load.

Displacements are in millimeter and stresses are in Pascal.

Flat plate

Case (1)

Case (2)

Case (3)
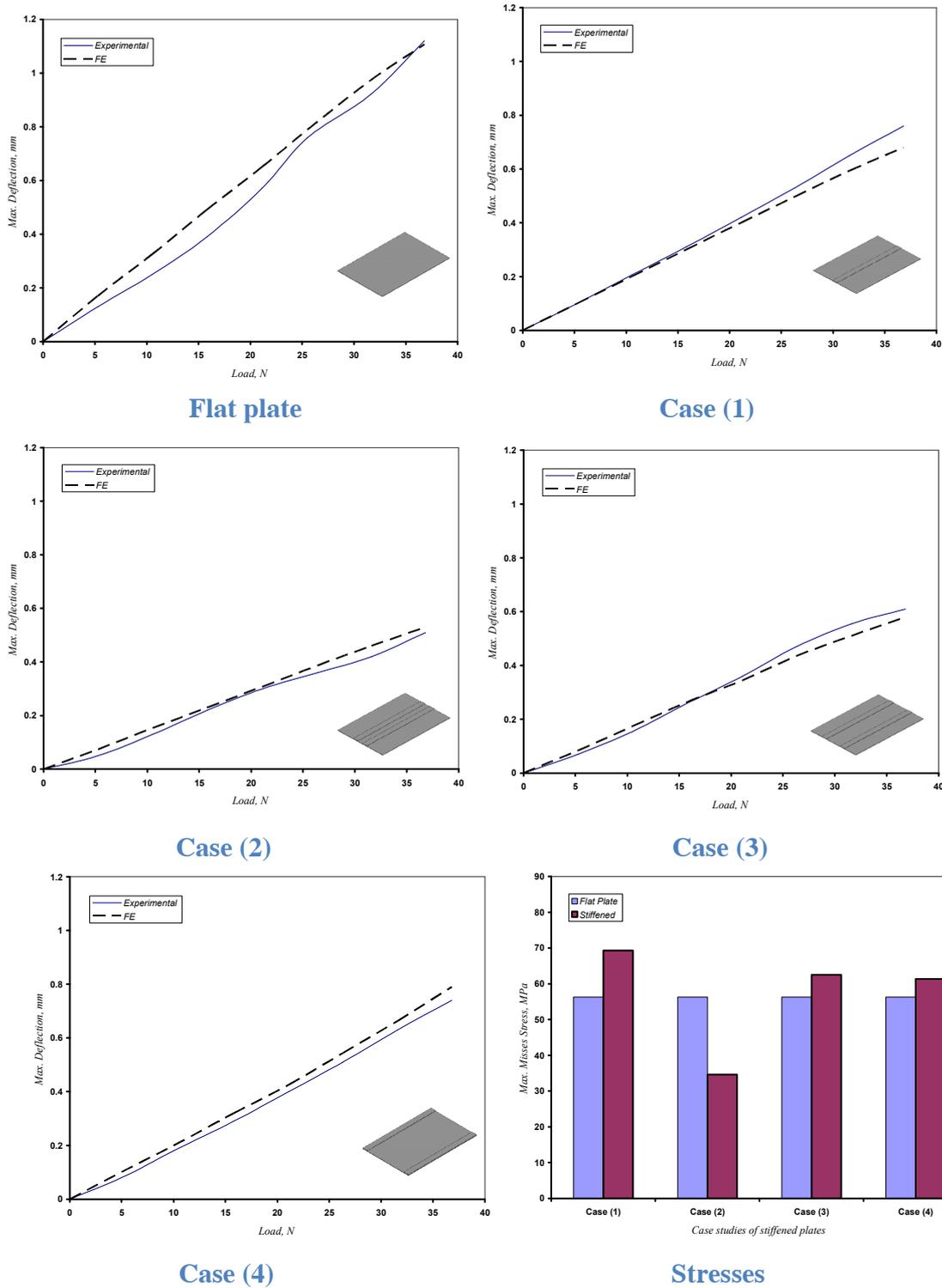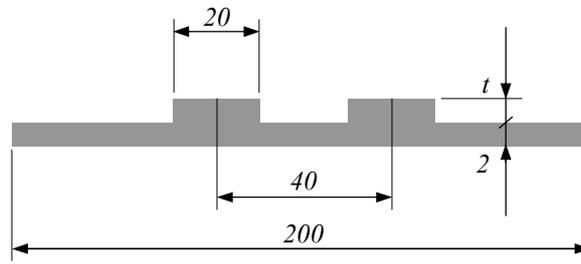
Case (4)

Stresses

Figure (4) Results of the experimental tests and FEA

5. Further Investigation :

Based upon the results, advanced analysis may be presented to study the strengthened plate with two neighbored ribs, which is the best case. Thickness of the rib (t) is studied numerically (see figure 5).

Figure (5) A view of the strengthened plate with two neighbored ribs, dimensions are in millimeter
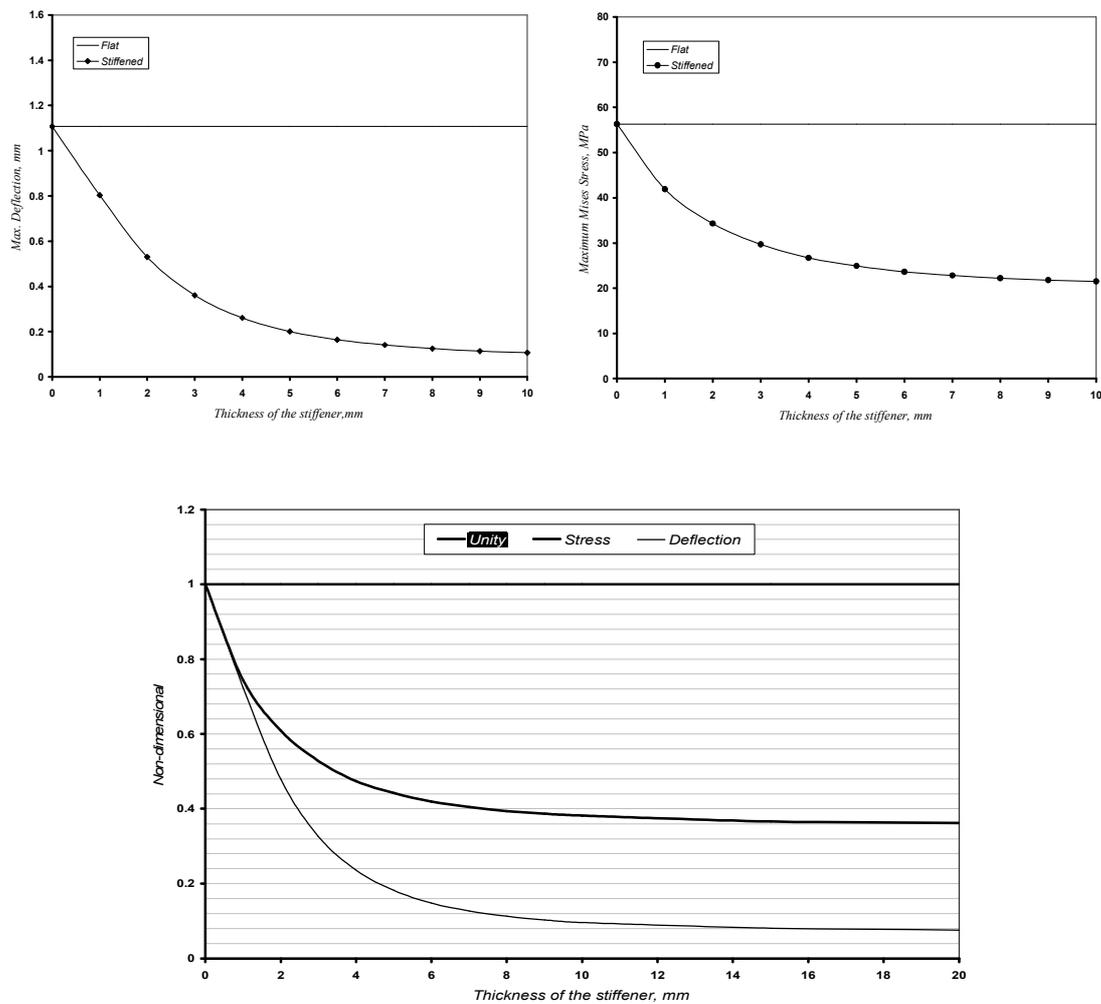
Figure (6) Effect of the thickness of ribs

Conclusions

There were several ways to increase the strength of plates. One of these ways is the use of stiffeners. Stiffeners are used not only to strengthen the plates, hulls, structures, and other parts, but they also used to minimize the weight and cost. For these reasons and others, strengthening plates by using of longitudinal ribs is one of the important and practical ways and need to deep investigation. Position, number and dimensions of the stiffeners play an important role to get optimum results. As it is noted from the results of this scientific research, there is an optimum use of these factors or in the other side; it may be no intention to use ribs. In this work, strengthening of

the plate with two parallel ribs and a certain thickness at a small span give best results, whereas other choices give poor results. No doubt the modification in boundary conditions may change these results, so more studies are recommended for other cases.

References

[1] Michael B. Prime, Michael R. Hill, "Residual Stress, Stress Relief, and Inhomogeneity in Aluminum Plate," Journal of Scripta Materialia, vol. 46, No. 1, pp. 77–82, 2002.

[2] Schade H. A., "The orthogonally stiffened plate under uniform lateral load," Journal of Applied Mechanics ASME, vol. 62, No. 14, pp. 3–6, 1940.

[3] Kendrick S., "The analysis of a flat plated grillage," European Shipbuilding, No. 5,   pp. 4–10, 1956.

[4] Liew K. M., Lam K. Y. and Chow S. T., "Free vibration analysis of rectangular plates using orthogonal plate function," Computers and Structures, vol. 34, pp. 79–85, 1990.

[5] Liew K. M., Xiang Y., Kitipornchai S. and Meek J. L., "Formulation of Mindlin-Engesser model for stiffened plate vibration," Computer Methods in Applied Mechanics and Engineering, vol. 120, No. 3, pp. 39–53,1995.

[6] Xiang Y., Liew K. M. and Kitipornchai S., "Vibration of circular and annular plates with internal ring stiffeners," Journal of the Acoustical Society of America, vol. 100, No. 3, pp. 696–705, 1996.

[7] Liew K. M. and Lam K. Y., "Application of two-dimensional orthogonal plate function to flexural vibration of skew plates," Journal of Sound and Vibration, vol. 139, No. 2, pp. 41–52, 1990.

[8] Deb A. and Booton M., "Finite element models for stiffened plates under transverse loading," Computers & Structures, vol. 28, No. 3, pp. 61–72, 1988.

[9] Biswal K. C. and Ghosh A. K., "Finite element analysis for stiffened laminated plates using higher order shear deformation theory," Computers & Structures, vol. 53, No. 1, pp. 61–71, 1994.

[10] Sadek E. A. and Tawfik S. A., "A finite element model for the analysis of stiffened laminated plates," Computers & Structures, vol. 75, No. 3, pp. 69–83, 2000.

[11] Rossow M. P. and Ibrahimkhail A. K., "Constraint method analysis of stiffened plates," Computers & Structures, vol. 8, pp. 51–60, 1978.

[12] Belytschko T. and Lu Y. Y., Gu L., "Element-free Galerkin methods," International Journal for Numerical Methods in Engineering, vol. 37, No. 2, pp. 29–56, 1994.

[13] Chen J. S., Pan C., Wu C. T. and Liu W. K., "Reproducing kernel particle methods for large deformation analysis of nonlinear structures," Computer Methods in Applied Mechanics and Engineering, vol. 139, pp. 195–227, 1996.

[14] Liew K. M., Lim H. K., Tan M. J. and He X. Q., "Analysis of laminated composite beams and plates with piezoelectric patches using the element-free Galerkin method," Computational Mechanics, vol. 29, No. 4, pp. 86–97, 2002.

[15] Ren J., Liew K. M. and Meguid S. A., "Modelling and simulation of the superelastic behaviour of shape memory alloys using the element-free Galerkin method," International Journal of Mechanical Sciences, vol. 44, No. 2, pp. 393–413, 2002.

[16] Wang J., Liew K. M., Tan M. J. and Rajendran S., "Analysis of rectangular laminated composite plates via FSDT meshless method," International Journal of Mechanical Sciences, vol. 44, No. 12, pp. 75–93, 2002.

[17] Lam Y.C., and Santhikumar S., "Automated rib location and optimization for plate structures," Journal of Structural and Multidisciplinary Optimization, vol. 25, No. 1, pp. 35–45, 2003.

[18] Carlos Graciano and Bernt Johansson, "Resistance of longitudinally stiffened I-girders subjected to concentrated loads," Journal of Constructional Steel Research, Volume 59, Number 5, pp. 561-586, 2003.

[19] Peng L. X., Kitipornchai S. and Liew K. M., "Analysis of rectangular stiffened plates under uniform lateral load based on FSDT and element-free Galerkin method," International Journal of Mechanical Sciences, vol. 47, pp. 251–276, 2005.

[20] Zoltán Virág, "Optimum design of stiffened plates for different loads and shapes of ribs," Journal of Computational and Applied Mechanics, vol. 5, No. 1, pp. 165–179, 2007.

[21] Radovi! L. J., Nika"evi! M., Popovi! M. and Romhanji E., "The influence of thermomechanical treatment and chemical composition on recrystallization of Al-Mg alloys," Journal of Metallurgy, pp. 260–266, 2007.

[22] Moreira, Pastrama and de Castro, "Three-dimensional stress intensity factor calibration for a stiffened cracked plate," Engineering Fracture Mechanics, vol. 76, pp. 2298–2308, 2009.

[23] Li Li and Ren Xiaohui, "Stiffened plate bending analysis in terms of refined triangular laminated plate element," Journal of Composite Structures, vol. 92, pp. 2936–2945, 2010.

[24] Shepard T., Raghunathan N., "Microstructure Evolution of the Hot-Rolled Modified AA 5083 Alloys During the Two Stage Thermal Treatment," 4th International Conference Processing and Structure of Materials, Serbia, 2010.

[25] Humphreys F.J., Hatherely M., "Recrystallization and Related Annealing Phenomena," Elsevier Science and Technology, pp. 668, London, 2004.