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# Buckling and bending properties of aluminium plate with multiple cracks

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## ABSTRACT

**Purpose:** In this paper, the bending strength and buckling stability of (AA 7075-T6) aluminium plate weakened by many transverse cracks, which located at different positions, subjected to concentrated loads applied at the ends were analysed.

**Design/methodology/approach:** Numerical modelling and calculation by the finite element method (ANSYS Package), for the critical load of bending and compression panel were estimated.

**Findings:** It found that the variation of the critical stress in bending and buckling is proportional to the crack conditions (no. of crack and location). In general, the critical load in bending and buckling decreases with increasing the crack number in structure.

**Research limitations/implications:** For both bending and buckling, two transverse cracks on one face of plate is more stable than two transverse cracks on opposite faces.

**Practical implications:** In addition, many experimental tests were carried out by using an INSTRON test machine to obtain the buckling critical loads, where the experimental results were compared with the ones of the finite element method. Furthermore, bending strength was calculated theoretically for the cracked panel.

**Originality/value:** Comparison between the experimental and numerical (FE based model) data and between the theoretical and nu-merical (FE based model) data for buckling and bending strength respectively indicate the precise and the simplicity of the developed models to determine the critical loads in such cases.

**Keywords:** Buckling stability, Bending strength, Crack, Aluminium plate, ANSYS package

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## METHODOLOGY OF RESEARCH, ANALYSIS AND MODELLING

## 1. Introduction

One of the main demands imposed on components and structures is that they have both strength and stability. Stability is the capability of component to resist the action of different forces which try to lead it out of a state equilibrium. Buckling is one of the fundamental forms of instability structure. In practice, buckling is described by a sudden failure of structure component subjected to compressive load [1]. Plates one of the most widely spread structural parts used in the majority of thin walled structures, that deal with many fields such that naval architecture, civil, mechanical, and aerospace engineering. Bridges, hydraulic structures, ships and off shore structures are some examples of complicated thin walled structures which comprise of plate elements, that are often exposed to various of force combinations like compression, bending, shearing and tensile loads under certain conditions, such loads can be caused plate fail or buckling [2]. Firstly, investigates concentrated on the find of the critical buckling load in the linear elastic region, but practical investigations revealed that the buckling capability of thin plats is much lower than the amount specified in the classic theories [3,4]. Plats, similar to other kinds of components, are often susceptible to different kinds of flaws or damages like cracks due to corrosion, chemical attack, fatigue, impact and creep, that weaken their structural soundness. Cracks in continuum materials act as stress raisers that generate infinite stress at the tip of crack [5]. The existence of cracks in a plate structure introduces a local flexibility. the crack stress intensity factor (SIF) was put into relation with the local flexibility of the cracked area of the component [6]. The stress intensity factor was determined in several cases, and a well-known relationship was discovered between the energy release rate, the stress intensity factor and the compliance of the cracked component. The local flexibility can be influence on static and dynamic response of plate structure. It may play the role of geometrical imperfection and consequently decrease the load carrying capacity of the plate [7]. In other word, cracks lower the structural integrity and should be considered in the stability analysis of cracked structures. Thus, it is of crucial importance, from several design and safety criteria, to investigate and recognize both stability and strength of such cracked plate structures. The importance is well realized on the failure accidents which have cause the loss of life. recently, the strength properties and buckling behaviour of cracked plates have received more attention by many researchers [8-12]. A number of studies have investigated the problem under tensile loads [13,14], thermal loads [15,16], and cyclic impact loading [16,17]. Over the years, many researchers were made the fairly comprehensive representation of the methods for tackling the cracked plate problems. Experimental, theoretical and numerical approaches were employed to tackle this problem. One of the widest spread numerical method used to treat with strength and buckling problems is finite element method [18-22]. Finite element method has been accounted one of the preferable techniques for tackling a wide difference of practical problems efficiently. It can be employed to solve any problem easily by altering the input data. Over the last 30 years, much attempts were carried out to study and treating the observed disadvantages of finite element method where the finite element analysis is one of the most common methods to treating the crack problems. In current work, linear analysis, by utilize the finite element based ANSYS17 software, was performed to investigate the influence of the crack location, and cracks number on the buckling and bending behaviour of thin plates. In addition, many experimental tests were carried out by using an INSTRON test machine to obtain the buckling critical loads, where the experimental results were compared with the ones of the finite element method. Also, theoretical calculations for bending strength were considered in current work.

## 2. Materials and methods

### 2.1. Materials

An aluminium alloy plate of grade (AA 7075-T6) was used in current work to perform the bending and buckling analysis. The chemical composition of used alloy illustrates in Table 1.

### 2.2. Specimen preparation

Free crack (virgin) and cracked samples were cut from the Al plate by utilize CNC cutting tool machine and prepared according with ASTM-E8 (Fig. 1) to carried out the uniaxial tensile test in order to obtained the required mechanical properties. The crack geometry and dimensions are presented in (Fig. 2a) The classification and designation of each tensile test specimen according to crack conditions (no. of crack and location) illustrate in Table 2. Then, plates with dimension of (50x20x6) mm and having the same tensile test specimen designation (Figs. 2b-f) were prepared to perform the bending and buckling tests.

Table 1.
The chemical compositions of Al-7075 alloy, w.t

| Si | Fe | Cu | Mn | Mg | Cr | Zn | Ti | Other | Al |
|---|---|---|---|---|---|---|---|---|---|
| 0.40 | 0.50 | 1.2-2.0 | 0.30 | 2.1-2.9 | 0.18-0.28 | 5.1-6.1 | 0.20 | 0.15 | Remainder |

Table 2.
Sample designation and tensile test result

| Samples designation | Number and Position of cracks | Fy, N | Fu, N | σy, MPa | σu, MPa |
|---|---|---|---|---|---|
| $A_1$ | Without crack | 34000 | 37900 | 453.33 | 505.33 |
| $A_2$ | One centre crack | 23000 | 28700 | 306.67 | 370.67 |
| $A_3$ | Two centre cracks on opposite plate faces | 27000 | 31900 | 360 | 425.33 |
| $A_4$ | Two cracks on one plate face | 28000 | 33100 | 373.33 | 441.33 |
| $A_5$ | Two cracks on opposite plate faces | 23500 | 25900 | 313.33 | 345.33 |

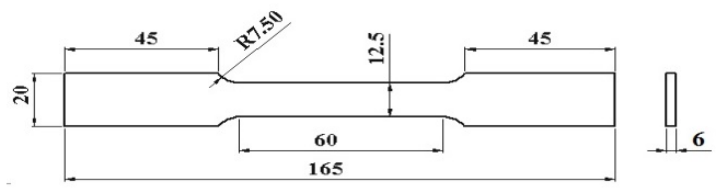


Fig. 1. Tensile specimen

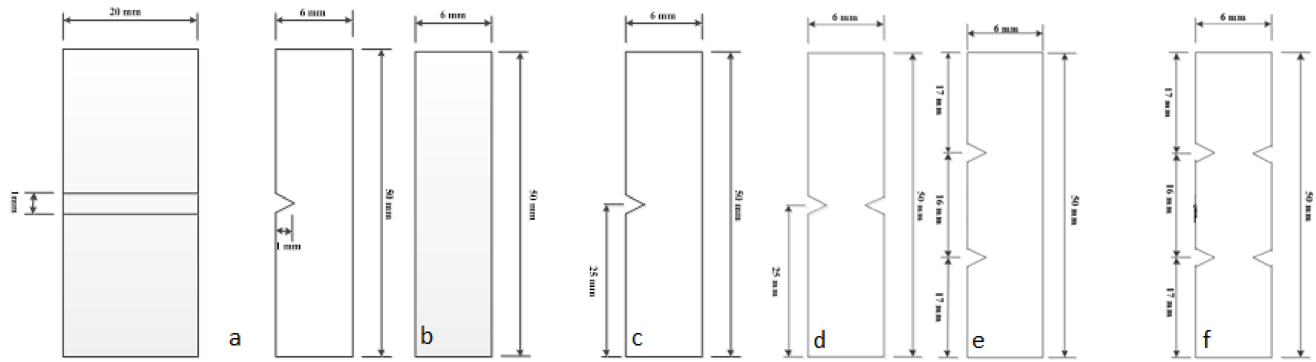


Fig. 2. cracks geometry, location, and dimension for each sample designation, a) crack dimension, b) A1, c) A2, d) A3, e) A4, f) A5

### 2.3. Methods

Uniaxial INSTRON tensile testing machine with loading capacity of 50 kN was used to carried out the tensile test. The specimens were mounted vertically in machine test and hydraulically pulled with big steel grips until fracture.

The buckling test was performed by loading the buckling specimen in axial compression using the same machine of tensile test. The specimen was loaded with incremental rate of 1 mm/min at the moveable end of the machine until occur the buckling.

## 3. Finite Element Model

Model description

The finite element method has been utilized for the modelling and analysis the bending strength and buckling behaviour of the cracked plates. A finite element program was build up and proposed for using in current work to investigate the cracked plate models. The input information of the model was read by the prepared program for evaluate and then make all steps required for pre-processing, analysis and post processing. These involve define the geometry, generate the mesh, applying end and loading conditions, carrying out the bending and buckling analysis and lastly post-processing tasks. The modelled plates possess different crack number, and position. The models were developed in ANSYS 17.0 by utilizing the element named SHELL281 as illustrate in Figure 3 that is used for meshing procedure. This element is proper for analysis thin-walled structures to moderately thick structures. The element possesses 8 nodes with 6 degree of freedom at each node: translations in the nodal x, y, and z directions and rotations about the x, y, and z-axes. The element possesses plasticity, stress stiffening, large deflection, and large strain capabilities. Material properties and geometry definition used in build up the model are listed in Table 3.

Table 3.
Geometric and material characteristics of Al plate

| | |
|---|---|
| Element type | 3D |
| Element name | SHELL281 |
| Geometry type | Plane stress-Solid |
| Material | Isotropic |
| Width | 20 mm |
| Depth | 6 mm |
| Span | 50 mm |
| Boundary condition | Simply supported |
| Poisson's Ratio | 0.33 |
| Density | 2810 kg/m$^3$ |
| Modulus of elasticity | 71.7 GPa |

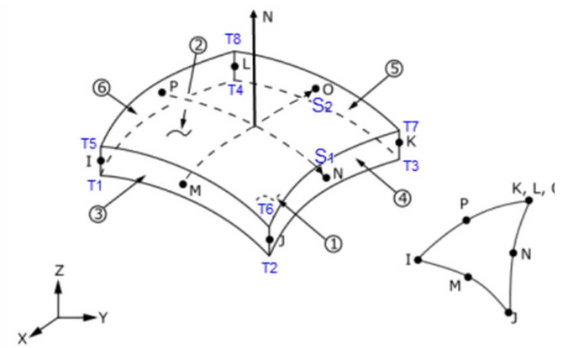

Fig. 3. SHELL281 geometry

## 4. Theoretical calculations

MDESIGN Software Package

MDESIGN is an effective tool for engineers and designers which strongly improves their productivity to make new mechanical parts and developing the present designs.

MDESIGN is a set of standardized parts and independent units which conduct complicated calculations that widely needed in mechanical design. It is consisting of an input sheet, a graphical tool, built-in databases for standard materials, and a system of prompting for needed inputs. In the current study, the geometrical information, and experimental data for tensile tests were fed to MDESIGN software package to obtaining the stress intensity factor, Kt, values and performing all theoretical calculations for bending strength.

## 5. Results and discussion

### 5.1. Bending strength

In order to evaluate the magnitude of the bending stress and because the width of plate is relatively small as compared with the length of plate, equation of the simple theory of elastic bending states was used to compute the theoretical value using the design parameters shown in the Table 4. where Kt is stress intensity factor and calculate by using MDesign program. Figures 4a-e display bending simulation of all sample conditions. Figure 5 summarize the effect of existence cracks and location on bending strength.

It is clear that the existence of the crack in plate structure generally leads to reduce the bending strength of plate. Moreover, it is evident that the location and number of crack also have strong effect on bending strength. The bending strength have inverse proportional with the number of cracks. It is noticed that the bending strength of sample A4, which have two cracks on the same face, higher than that of sample A5, which have central two cracks on opposite faces.

Table 4.
The design parameters and theoretical results of bending strength for all samples

| Sample | Force, N | Length, mm | Width b, mm | Height h, mm | $K_t$ | Bending stress, MPa |
|---|---|---|---|---|---|---|
| $A_1$ | 6960 | 50 | 20 | 6 | - | 1450 |
| $A_2$ | 3700 | 50 | 20 | 6 | 1.66 | 1279.58 |
| $A_3$ | 2490 | 50 | 20 | 6 | 1.66 | 861.13 |
| $A_4$ | 2730 | 50 | 20 | 6 | 1.66 | 944.125 |
| $A_5$ | 1930 | 50 | 20 | 6 | 1.66 | 402 |

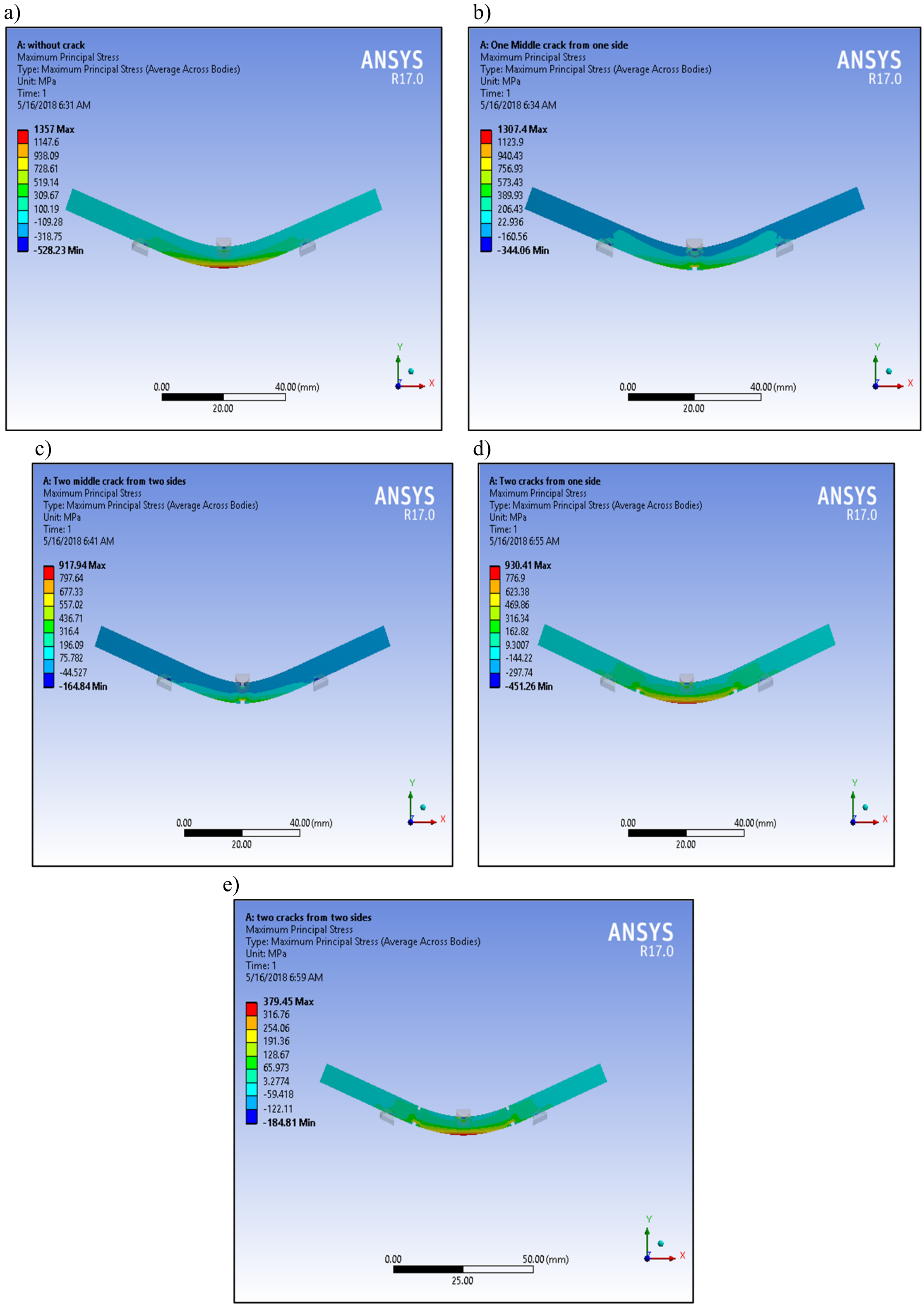


Fig. 4. Bending simulation results of samples, a) A1, b) A2, c) A3, d) A4, e) A5

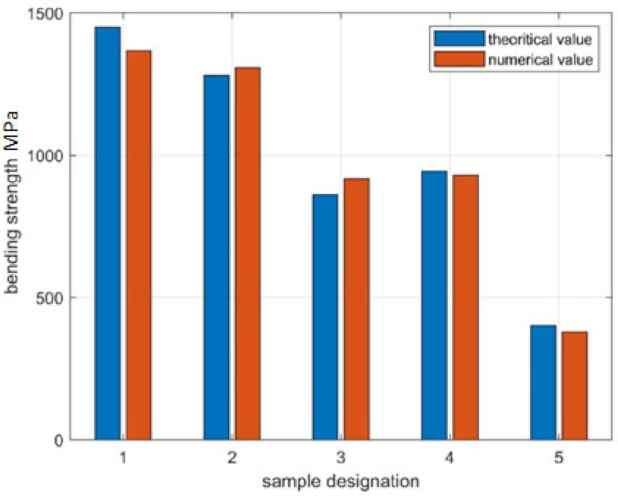


Fig. 5. Theoretical and numerical values of bending strength for each crack conditions

This means when change the crack position, from the centre and transferred vertically toward one of the ends of the plate the critical load enhanced, meaning that the system is more stable. This behaviour may be attribute to the decreasing the area between the two opposite cracks that lead to weaken the resistance of plate to applied load. Also, Figure 5 indicates that there is a good agreement between the theoretical and numerical results. This suggested that the proposed model has high accuracy in predicting the bending behaviour of cracked plates.

### 5.2. Buckling stability

The results of experimental buckling tests were presented in Figures 6 and 7a-e, while the numerical results were presented in Figures 8a-e. Figure 9 summarize the crack effect result and displays a comparison between experimental and numerical results. It is evident with presence the crack in plate, the critical load affected significantly. Critical load of plate decreases with increasing the number of cracks in plate structure. When the sample has two cracks on centre, it is failed at a load which is lower than of sample has one crack at centre. This is because the internal weakness for the plate having two cracks at centre is greater than the plate having one crack at centre.

Once the number of crack is constant, noticing the critical load also affected with alternating the crack position. It is observed that the critical load for samples having two cracks at the mid-span is lower than ones having two cracks away from the centre (sample A4). Note that the more the crack converge to the mid span the more the critical load reduces. This is associated with the stresses distribution and because of the value of moment is maximum at the mid span for pinned ends support conditions.

Figure 9 shows a comparison between the numerical and experimental results. This comparison indicates the satisfactory precise of the current study where little differences were observed between experimental and numerical outcome. This is showed that the proposed model is efficient and powerful to analysis the elastic stability of cracked plates.

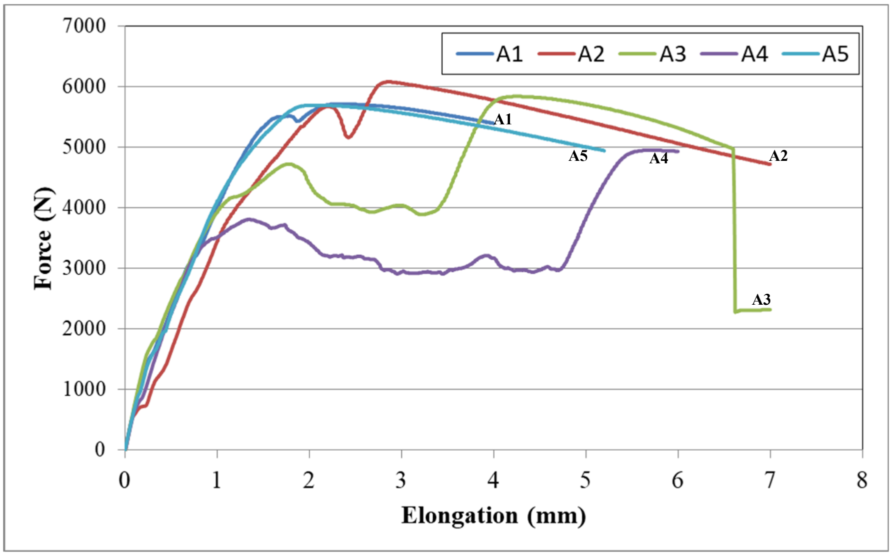


Fig. 6. Combining experimental results of buckling test of samples

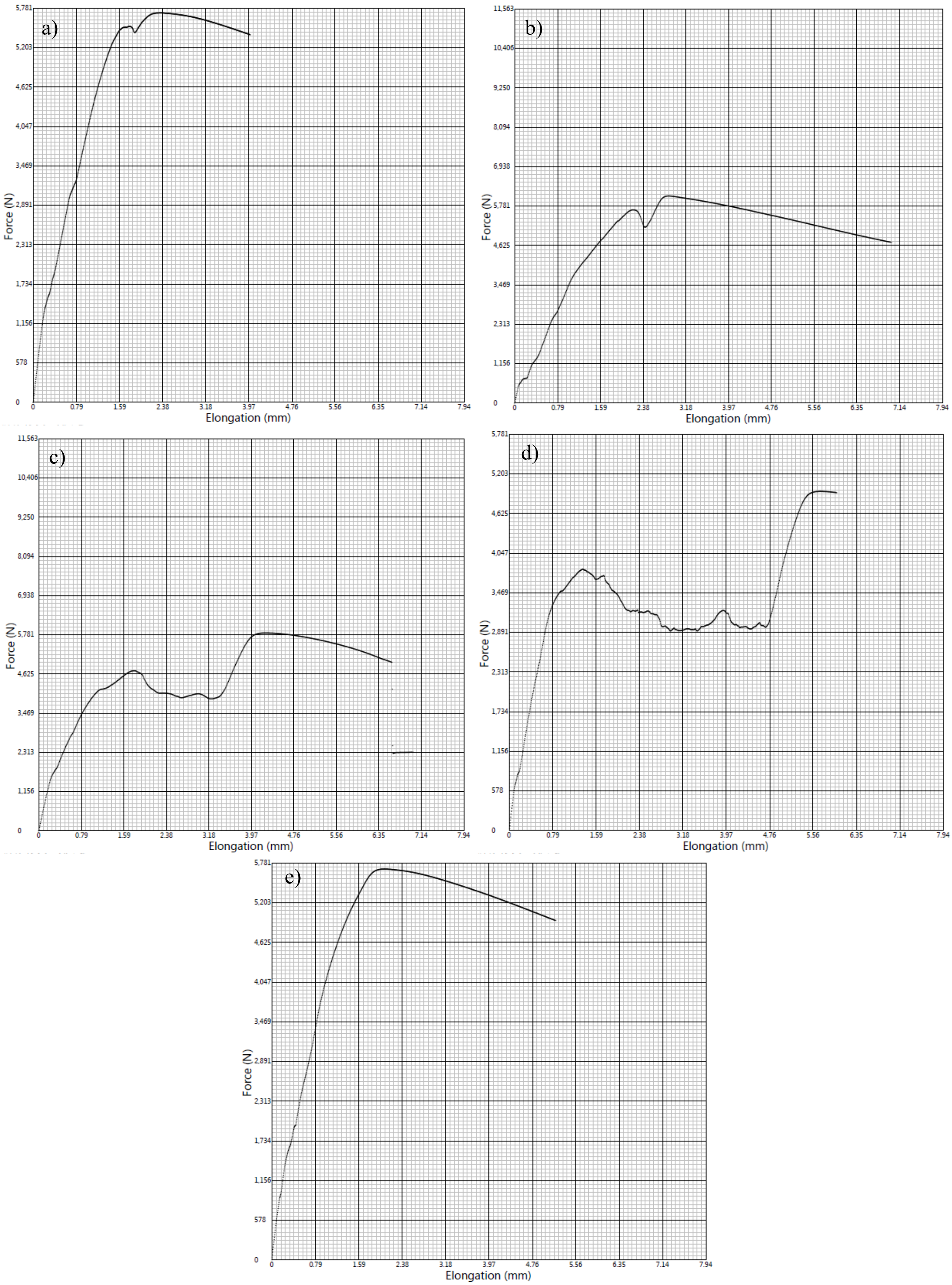


Fig. 7. experimental results of buckling test of samples, a) A1, b) A2, c) A3, d) A4, e) A5

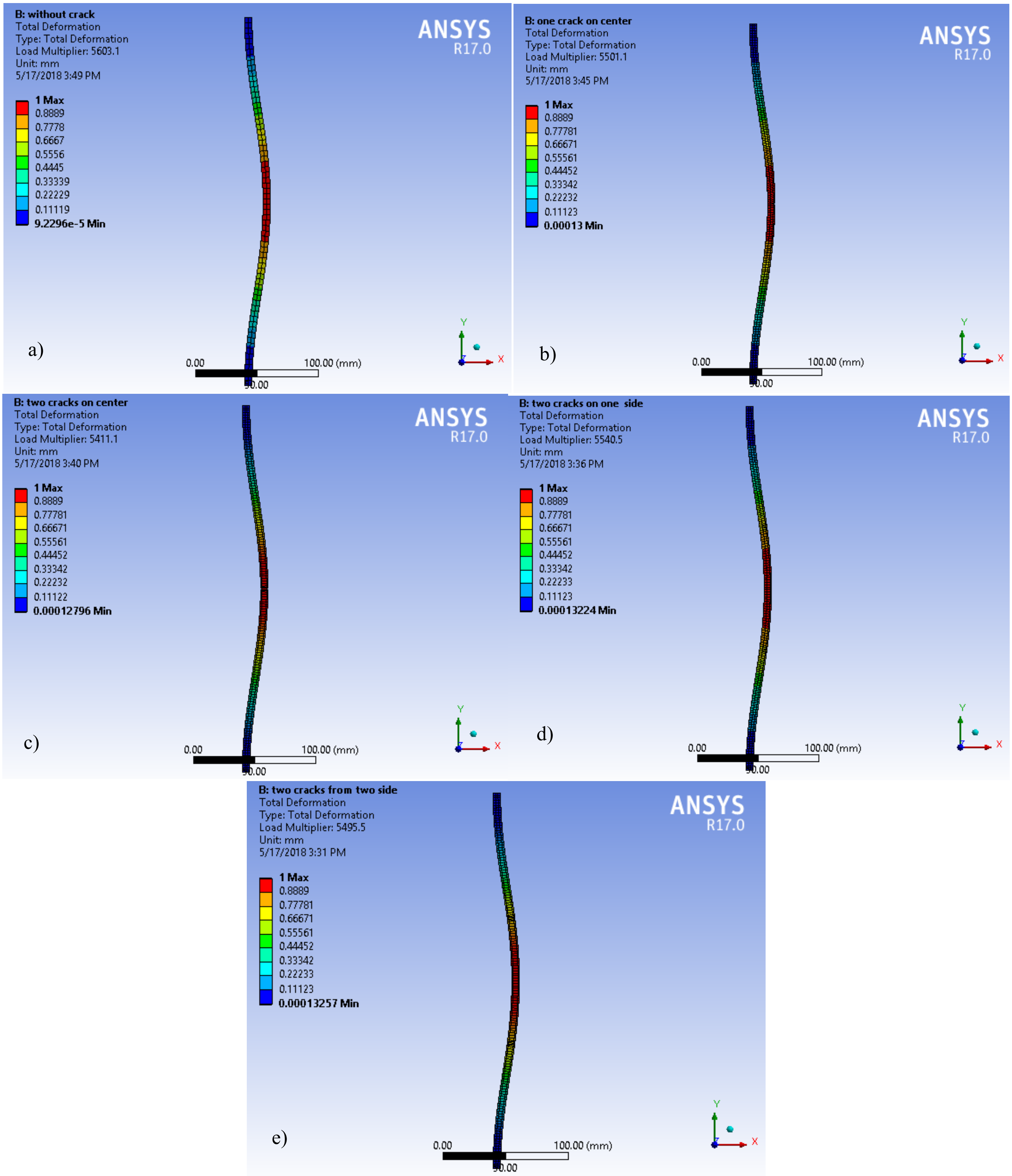


Fig. 8. Buckling simulation of samples, a) A1, b) A2, c) A3, d) A4, e) A5

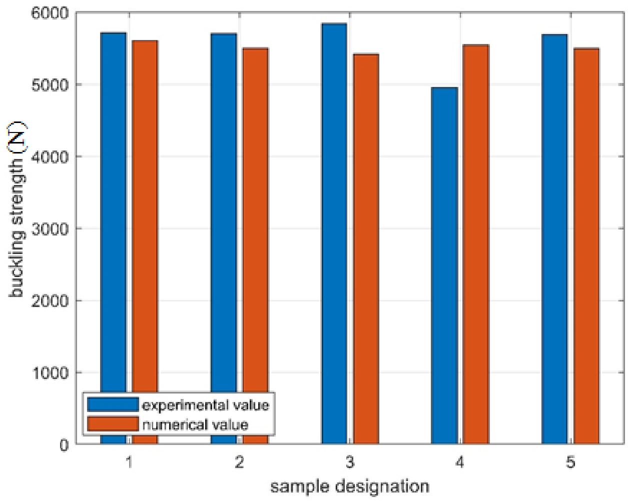


Fig. 9. Experimental and numerical values of buckling for each crack condition

## 6. Conclusions

In current study the effect of the presence of crack on the bending strength and buckling of (AL7075-T6) aluminium plate has been analysed. The following conclusions can be drawn by the analysis, results, and discussion of this paper:

1. It is evident that the crack damage decreases the critical load of the specimen of bending and buckling significantly.
2. The critical load of bending and buckling decreases prominently as the number of crack increases, especially, when the specimen has cracks from two sides.
3. The critical buckling and bending load decrease because of the existence of the cracked regions. The reduction amount in the buckling and bending load depend on the number and position of the crack. That a dramatic reduction in the critical load of bending and bulking may be obtained by using 2 or more cracks in the design.
4. For both bending and buckling, two transverse cracks on one face of plate is more stable than two transverse cracks on opposite faces.
5. A good agreement has been obtained by comparing the theoretical, numerical and experimental results of critical loads for both bending and buckling. This suggested that the proposed models for bending and buckling are efficient and powerful to analysis the elastic stability and predicting the critical loads of bending and buckling for the cracked plates.

In summary, this paper has shown that strength is decreased by founding of cracks in the section. This is associated with concentration of stress in the crack location. The same trend was observed with increase the number of cracks.

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