Theoretical Stress Analysis of Gas Turbine Blade Made From Different Alloys

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ABSTRACT
Blades may be considered to be the heart of turbine without blade there would be no power and the slightest fault in blade would mean a reduction in efficiency and costly repairs. The centrifugal force is one of the problems faced by the designer of blades especially at the first stages. The designer aims at reducing the stresses with in the allowed limit. The ANSYS 15 software was used as far as it is the most effective in analyzing the different numerous cases of stresses, the blades with limited root in all direction (X,Y,Z) were taken into consideration. The centrifugal forces were applied on the rotor blades at running speed of 6000 r.p.m., The finite element models of the blade were constructed using D3-10-noded Tetrahedron elements shape, SOLID 187, mesh of the entire blade 23406 Node,136575element. The average of normal stress, Von misses, Maximum principle stress, Minimum principle stress were calculated according to ANSYS 15 program, these stresses are as the result of the effect of centrifugal force for all planes along the blades and then values of stresses were compared to the curves for each alloy. The current research concluded that the Titanium alloy is the best alloy used in terms of reducing stresses due to centrifugal force, that is because density of Titanium alloy used is less than that of other used alloys, leading a reduction in centrifugal forces that are directly proportional to mass.

Keywords:
Gas turbine blade; inconel 625, inconel 718 MarM-200; Titanium alloys; Centrifugal stress; ANSYS15; Stress analysis.

1. INTRODUCTION
Shattering of turbine blades are one of the most critical troubles in power generating industry. Rotor blades are the very generally used machine parts used in high-technics applications and in general are used as a lot of arrangement mechanical element. These blades are subjected to different loads like centrifugal loading. Centrifugal forces is the main component participate in to the stress produced in the blades [1].

Centrifugal loads are formed by high rotational speeds at (6000 r.p.m).The formed Centrifugal force depend upon the size of the rotor and the rotational speed of the rotor. As it is well known, that the centrifugal force Fe can be defined as :

\[ Fe = mrw^2 \]

where, \( m \) is the mass (kg), \( r \) is the radius of rotation and \( w^2 \) is the angular speed. Gas turbine blades alloys are designed mainly to protect the structural material against loads, corrosion, oxidation, erosion and high temperature environments.

The main reason of shut down in turbo machine is the shatter of rotor blade. The failure of the rotor blade may guide to serious consequences both physically and economically. Hence, the suitable design of the turbo machine blade plays a necessary role in the suitable functioning of the turbo machine [5].
In the current study, the first stage rotor blade of a two-stage gas turbine has been analyzed for structural static using ANSYS 15.0 Software which is powerful Finite Element Software. In the process of getting mechanical stresses in the rotor blade has been evaluated using four different alloys; namely: Inconel 718, Inconel 625, MarM200, Titanium alloys. And the dimensions of the blade for the current study shown in Table.1. The blade was cut into twenty one sections along the length of the Airfoil with ANSYS software as shown in Fig.1. The finite element models of the blade were constructed using D3-10-noded Tetrahedron elements shape, SOLID 187, mesh of the entire blade 23406 Node, 136575 element as shown in Fig. 2. And all results take from the option of the average of stresses in ANSYS software as shown in Fig.3.

Table 1: Dimensions of the blade

| Total length of blade | Length of root | Length of Airfoil | Length of hollow |
|-----------------------|----------------|-------------------|------------------|
| 157mm                 | 62mm           | 95mm              | 52.1mm           |

2. LITERATURE REVIEW

Theju et.al[8] had mainly done the research work on jet engines turbine blade; the study was done on two different materials Inconel718 and Titanium T-6 alloy to discuss the effect of temperature and induced stresses on turbine blade. The study complemented that the Titanium T-6 would have minimum value of deformation and lesser strength.

Naga Bhushana Rao et.al[9] had done research on turbine blade used in marine applications. The blade was observed for structural analysis at elevated temperatures and under the action of large centrifugal force, the material used was nickel based super alloy, it was investigated that high stresses and strains were observed near to the root of the turbine blade and upper surface along the blade root, maximum temperature is observed at the blade tip and minimum at the root of the blade.

3. MATERIAL AND MATERIAL PROPERTIES

Four alloys have been used in the current study:

3-1- INCONEL 718 & INCONEL 625 alloys

It is a high strength, heat resistant superalloy (HRSA) that is used extensively by the aerospace industry for the hot parts of gas turbine engines such as, turbine disks, blade [2].

3-2-Mar M-200 alloy

The material of the blade is taken as MAR M-200 is consider superNickel alloy. It is one of the proper material for blades of Gas turbine on account of its altitude yield strength,
endurance limit and its ability to stop the rising of temperatures [1].

3.3-Titanium Alloy
Accelerates formation of chromia at metal/oxide interface; decrease thermal expansion coefficient in Ni base alloys. These titanium alloys are fundamentally used for represent materials for hard tissues.[3].

Table 2: Mechanical properties of Inconel 625, MarM-200 & Titanium alloy [6,4,1,3].

| Property                | Inconel625 alloy [6] | Inconel718 alloy [4] | MarM200 alloy [1] | Titanium alloy [3] |
|-------------------------|----------------------|----------------------|-------------------|-------------------|
| Density (kg / m³)       | 8400                 | 8190                 | 8526              | 4540              |
| Poisson’s ratio         | 0.3                  | 0.22                 | 0.33              | 0.33              |
| Modulus of Elasticity (Gpa) | 145                  | 200                  | 220               | 206.84            |

4. RESULTS AND DISCUSSIONS
Following Fig.(4,6,7) show the results of stress analysis in INCONEL625 alloy, we notice that the concentration of stresses rate is in the back of the base of the airfoil, which gradually decreases along the airfoil near the top of the blade, because the centrifugal force is higher at the base and lower at the top of the blade due to the decrease in the mass of blade whenever the direction from the base to the top of the blade and Table(3) show the average stresses on INCONEL625.

Fig. 4 Shows the maximum principle stress for INCONEL625 alloy.

Fig. 5 Shows the minimum principle stress for the INCONEL625 alloy blade.

Fig. 6 Shows the normal stress for the INCONEL625 alloy blade.

Fig. 7 Shows the Von misses stress for the INCONEL625 alloy blade.
Table 3: Results of average stress analysis of blade of gas turbine made from INCONEL625 alloy by ANSYS program at all sections along the blade.

| Section No. | Normal stress (MPa) | Von misses (MPa) | Maximum principle stress (MPa) | Minimum principle stress (MPa) |
|-------------|---------------------|-----------------|--------------------------------|-------------------------------|
| 1           | 11942               | 10300           | 12510                          | 2520                          |
| 2           | 11700               | 10240           | 12030                          | 1022                          |
| 3           | 11034               | 10250           | 11110                          | 239                           |
| 4           | 10362               | 9950            | 10410                          | 40                            |
| 5           | 9662                | 9454            | 9714                           | 12                            |
| 6           | 8940                | 8865            | 9005                           | 11                            |
| 7           | 8197                | 8201            | 8276                           | -1                            |
| 8           | 7428                | 7452            | 7521                           | -108                          |
| 9           | 6666                | 6939            | 6853                           | -422                          |
| 10          | 6198                | 8243            | 6321                           | -2367                         |
| 11          | 9423                | 9399            | 9480                           | -124                          |
| 12          | 8517                | 8592            | 8579                           | -148                          |
| 13          | 7602                | 7727            | 7666                           | -121                          |
| 14          | 6678                | 6831            | 6744                           | -296                          |
| 15          | 5748                | 5917            | 5811                           | -349                          |
| 16          | 4800                | 4997            | 4866                           | -395                          |
| 17          | 3846                | 4079            | 3914                           | -439                          |
| 18          | 3000                | 3174            | 2954                           | -488                          |
| 19          | 1908                | 2305            | 1999                           | -541                          |
| 20          | 1300                | 1539            | 1115                           | -600                          |
| 21          | 0.5                 | 1302            | 100                            | -788                          |

The following Fig. (8 to 11) show the stress analysis for INCONEL718 alloy, the result obtained can be discussed as an ANSYS program where the value of the largest stress at the base of the airfoil and the lowest at the top of the blade is explained by the fact the high centrifugal force at the base of the airfoil and less as we movement to the top of the blade, and Table(4) show the average stresses on INCONEL 718.
Table 4: Result of average stress analysis on blade of gas turbine made from INCONEL718 alloy by ANSYS program at all sections along the blade.

| Section No. | Normal stress (MPa) | Von misses (MPa) | Maximum principle stress (MPa) | Minimum principle stress (MPa) |
|-------------|---------------------|-----------------|-------------------------------|-------------------------------|
| 1           | 12263               | 10278           | 11700                         | 1664                          |
| 2           | 11423               | 10247           | 11680                         | 896                           |
| 3           | 10750               | 10125           | 10820                         | 234                           |
| 4           | 10101               | 9763            | 10150                         | 38                             |
| 5           | 9421                | 9240            | 9474                          | 7                              |
| 6           | 8716                | 8640            | 8782                          | 5                              |
| 7           | 7993                | 7983            | 8071                          | 4                              |
| 8           | 7241                | 7245            | 7335                          | -70                            |
| 9           | 6498                | 6716            | 6680                          | -331                           |
| 10          | 6060                | 8007            | 6192                          | -2263                          |
| 11          | 9187                | 9238            | 7245                          | -190                           |
| 12          | 8304                | 8400            | 4557                          | -168                           |
| 13          | 7412                | 7535            | 4525                          | -215                           |
| 14          | 6511                | 6655            | 4515                          | -280                           |
| 15          | 5600                | 5765            | 3684                          | -330                           |
| 16          | 4681                | 4868            | 2773                          | -373                           |
| 17          | 3709                | 3970            | 1865                          | -440                           |
| 18          | 2811                | 2799            | 1127                          | -460                           |
| 19          | 1860                | 2237            | 1121                          | -511                           |
| 20          | 899                 | 1488            | 1090                          | -572                           |
| 21          | 0.7                 | 1234            | 559                           | -748                           |

The following Fig. (12- to 15) show the result of MarM-200 alloy blade, the highest value of the stresses is at the base of the airfoil, the reason is that the centrifugal force are high at the base of airfoil and decrease as we move up at the top of the blade this is due to the gradual reduction of the blade mass along the airfoil, and Table(5) show the average stresses on MarM-200.

- Fig. 12 Shows the maximum principle stress for Mar-M200 alloy.
- Fig. 13 Shows the minimum principle stress MarM-200 alloy.
- Fig. 14 Show the normal stress for Mar M-200 alloy.
- Fig. 15 Show the Von misses stress for Mar M-200.
Table 5: Result of average stress analysis on blade of gas turbine made from Mar M-200 alloy by ANSYS program at all sections along the blade.

| Section No. | Normal stress (MPa) | Von misses stress (MPa) | Maximum principle stress (MPa) | Minimum principle stress (MPa) |
|-------------|---------------------|-------------------------|--------------------------------|-------------------------------|
| 1           | 12100               | 10400                   | 12690                          | 2558                          |
| 2           | 11880               | 10390                   | 12200                          | 1037                          |
| 3           | 11199               | 10412                   | 11280                          | 243                           |
| 4           | 10518               | 10101                   | 10560                          | 41                            |
| 5           | 9808                | 9596                    | 9859                           | 12                            |
| 6           | 9074                | 8996                    | 9140                           | 11                            |
| 7           | 8320                | 8324                    | 8400                           | -2                            |
| 8           | 7539                | 7564                    | 7633                           | -109                          |
| 9           | 6766                | 6743                    | 6956                           | -428                          |
| 10          | 6291                | 8367                    | 6415                           | -2402                         |
| 11          | 9564                | 9540                    | 9622                           | -126                          |
| 12          | 8644                | 8722                    | 8707                           | -150                          |
| 13          | 7716                | 7843                    | 7780                           | -224                          |
| 14          | 6778                | 6933                    | 6845                           | -300                          |
| 15          | 5831                | 6006                    | 5898                           | -354                          |
| 16          | 4873                | 5073                    | 4939                           | -401                          |
| 17          | 3905                | 4141                    | 3970                           | -446                          |
| 18          | 2926                | 3222                    | 2998                           | -495                          |
| 19          | 1937                | 2340                    | 2029                           | -549                          |
| 20          | 935                 | 1562                    | 1132                           | -609                          |
| 21          | 0.8                 | 1322                    | 606                            | -800                          |

The following Fig.(16-to19) result of TITANUM alloy blade; it was observed that the highest value of the stresses at the base of the airfoil and gradually decrease as the height reaches the top of the blade to reach the least value of the stresses where the stresses are located at the back of the base of the airfoil, and Table(6) show the average stresses on TITANUM alloy.

Fig. 16 Shows the maximum principle stress for TITANUM alloy blade.

Fig. 17 Shows the minimum principle stress for TITANUM alloy blade.

Fig. 18 Shows the normal stress for TITANUM alloy blade.

Fig. 19 Shows the Von misses stress for TITANUM alloy blade.
Table 6: Result of average stress analysis on blade of gas turbine made of TITANIUM alloy by ANSYS program in all sections along the blade.

| Section No. | Normal stress (MPa) | Von misses stress (MPa) | Maximum principle stress (MPa) | Minimum principle stress (MPa) |
|------------|---------------------|-------------------------|-------------------------------|------------------------------|
| 1          | 6637                | 5540                    | 6760                          | 1362                         |
| 2          | 6031                | 5535                    | 6504                          | 552                          |
| 3          | 5963                | 5530                    | 6004                          | 130                          |
| 4          | 5601                | 5379                    | 5625                          | 22                           |
| 5          | 5223                | 5110                    | 5250                          | 7                            |
| 6          | 4832                | 4791                    | 4867                          | 6                            |
| 7          | 4430                | 4433                    | 4473                          | 0                            |
| 8          | 4014                | 4027                    | 4064                          | -58                          |
| 9          | 3603                | 3750                    | 3704                          | -228                         |
| 10         | 3350                | 4455                    | 3416                          | -1279                        |
| 11         | 5097                | 5080                    | 5123                          | -67                          |
| 12         | 4603                | 4644                    | 4636                          | -79                          |
| 13         | 4109                | 4176                    | 4140                          | -119                         |
| 14         | 3609                | 3691                    | 3644                          | -160                         |
| 15         | 3105                | 3198                    | 3140                          | -186                         |
| 16         | 2595                | 2701                    | 2630                          | -214                         |
| 17         | 2079                | 2205                    | 2115                          | -238                         |
| 18         | 1559                | 1715                    | 1597                          | -264                         |
| 19         | 1031                | 1245                    | 1080                          | -292                         |
| 20         | 498                 | 831                     | 602                           | -324                         |
| 21         | 0.4                 | 704                     | 322                           | -426                         |

The following Fig.(21,22,23,24) comparison for all alloys used in current research. The concentration of the stresses is at the base of the airfoil for all the alloys used in this study, and the resulting stresses, such as normal stress, maximum, and minimum principle stress and von misses stress which were analyzed by the ANSYS software are lower in Titanium alloy than other alloys because the density of Titannium is less than the density of other alloys.
5. CONCLUSION

The results achieved due to the centrifugal forces on the blade is debated below.
1- It was conclusion that the stresses produced by the centrifugal forces (normal stress, maximum and minimum principle stress, von misses stress) were concentrated at the base airfoil from the back.
2- It was observed that stresses along the blade be higher value when back to the root and less at the top of the blade as shown in Fig.(21,22,23,24).
3- The centrifugal force depends on the mass where all less than the mass of the blade less centrifugal force and thus reduce the stresses resulting from this force, which was observed in the Titanium alloy of less density compared with the other alloys.
4- The tensile strength (normal stress) of the centrifugal force on the blade made of the Titanium alloy density is less than the tensile stress caused by the other alloys because the Titanium alloy density is lower than that of the other alloys this causes to reduce centrifugal force then causes to reduce stresses as shown in Fig.(21).
5- Maximum principle stress of the blade made of Titanium alloy has less than the maximum principle stress of the blade made of alloy s Inconel625, Inconel718, MarM-200) because the Titanium alloy density is lower than that of the other alloys so causes to reduce centrifugal force then causes to reduce stresses as shown in Fig.(22) & Fig.(4,8,12,16).
6- That the negative value of the minimum principle stress of all alloys used indicate that the blade is subjected to compression stress in some blade parts of all alloys used as shown in Fig.(23).
7- It was noted that the highest stress equivalent to the blade made of Titanium alloy is 26089Mpa, and the equivalent stress of the blade made of Inconel625 is 48271Mpa, and the highest equivalent stress of blade made of Inconel718 is 47631Mpa, and the equivalent stress on the blade made of MarM200 is 48995Mpa this shows that the best on the safe matter of the high stresses is the titanium alloy this is due to the fact that Titanium alloy density is less than the density of the alloys used as shown in Fig.(6,11,15,20).
8- It is conclusion that the Titanium alloy is the best alloy used in terms leading to reduce stresses due to centrifugal force, because density of Titanium alloy used is less than of other used alloys, so leading a reduction in centrifugal forces which are directly proportional to mass, there by reducing the stresses of these forces to the Titanium alloy that is density less than of the alloys used in this study.

9- It was noted that the results of stresses for the INCONEL718, INCONEL625 and MarM-200 alloys are closer, they are nickel base alloys and they have the nearest density.

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التحليل النظري لإجهاد أتريش التوربين الغازي المصنوع من سبائك مختلفة

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الخلاصة:

تعدّر الريش قلب التوربين ويكون الريش لا توجد طاقة وإن أي حال فيها يؤدي إلى انخفاض الكفاءة وتصنّيلات مكلفة. استخدمت الناصر المحددة (ANSYS15) لتحديد على حلول تقريبية لمجموعة واسعة من المشاكل الهندسية. يتم تحديد الإجهادات الميكانيكية باستخدام برنامج ANSYS15 وابداعة الأعاصير العالمية بوصفها إقلاع في تحليل الإجهادات المكلفة، إذ تم اختيار الرشتين من بمثابة مّرنة في جميع الإتجاهات (X,Y,Z) إضافة إلى الأعاصير الميكانيكية. وتستخدم برنامج (ANSYS15) لتحديد الريشة، قوى الطرد المركزى مطلقة على الرشتين لبجع عمودي من درزات الدور (6000 دورة / دقيقة). ثم بناء نماذج العناصر المحددة باستخدام (ANSYS15) عقد من نوع رياضي المنوحدة 87. وبنج إلى الناتج المحيط للكم출 من 23406 شريحة 

الكلمات المفتاحية: سبائك، انخفاض، التحليل الإجهاد