Technical Journal, University of Engineering and Technology (UET) Taxila, Pakistan Vol. 29 No. 2-2024
ISSN:1813-1786 (Print) 2313-7770 (Online)

Structural Integrity and Cost Analysis of a Connecting Rod for Articulated Robotic Arm Using Various Stainless Steel and Aluminium Alloys

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Abstract- With the advancement in technology in the recent past and the automation of industrial processes, the field of robotics has evolved significantly. Most of the processes on the industrial level and in aerospace sector are being done with the help of robots and robotic arms. Due to this, the strength and structural integrity of robots has become a critical topic for investigation. This study evaluates structural analysis and cost analysis to produce a connecting rod for an articulated robotic arm using Steel and Aluminium alloys. The model of a connecting rod is created in the SOLIDWORKS® whereas the simulation is done on ANSYS® at three-moment values i.e. 500 Nm, 600 Nm and 700 Nm respectively. 5 Steel alloys (i.e. 304L Stainless Steel, annealed 310 Stainless Steel, annealed 316L Stainless Steel, quenched 410 Stainless Steel and annealed 446 Stainless Steel) and 5 Aluminium alloys (i.e. Aluminium alloy 5052-H32, Aluminium alloy 5086-H34, Aluminium alloy 6061-T8, Aluminium alloy 6063-T83 and Aluminium alloy 7075-T76) are used for simulation. Deformation, strain and stress values for each alloy are calculated at the aforementioned moment values. The cost analysis is done based on the volume of the connecting rod and the material required to produce that connecting rod. The results showed that annealed 310 Stainless Steel is the best choice among the analyzed alloys for enhanced strength and reduced deformation. On the other hand, 5086 Aluminium alloy is economical for the production of connecting rods but its strength is much lower than that of Steel. 304L Steel alloy is economical and deformation closer to 310 Stainless Steel alloy but its factor of safety is significantly less than that of 310 Stainless Steel. So, the optimal material for the production of a connecting rod for an articulated robotic arm is 310 Stainless Steel.

Keywords- Robotic Arm, ANSYS, Connecting Rod, Cost Analysis, Structural Analysis, Material Selection.

I. INTRODUCTION

In the recent past, a surge in the field of robotics and the usage of robots has been recorded. The robots have started to get the jobs of humans, especially in applications which require the same work for many times. Robots may either be industrial robots or service robots [1]. Robotic arms have found numerous applications in the manufacturing industry, assembling applications, medical applications, etc. [2-3]. Kruthika designed and developed a 5 degree of freedom robotic arm which was intended to assist the special or old people for feeding purposes. They controlled the robotic arm through robotics kinematics and MATLAB® algorithms [4]. Roshaniafard and Noguchi designed and analyzed a 5 degree of freedom articulated robotic arm for agricultural purposes. The design and analysis were done on SOLIDWORKS®. They utilized different materials and evaluated torque values for different joints. The results demonstrated that changes in the material and location of the servo motor can improve the required torque for joints [5].

Vishal and Mohan performed a structural analysis of a 6-axis Kuka KR16 industrial robot using ANSYS® software. They varied the loads and analyzed the deformation values, stress values and strain values using finite element analysis. Based on the simulation at different loads, they identified the weak parts of the articulated robot which helped to improve the design of rebot [6]. In another study, Shi presented a mathematical model to determine the static stiffness of the EAST maintenance robotic arm. The results showed that the analyzed model produced an acceptable error of less than 5% which paved the way to use this model in other similar but complex robotic systems [7]. The optimized design of a robotic arm link was analyzed and studied by Mushiri and Kurebwa. Finite element method was utilized to optimise the structure design based on static analysis. They also presented a way of tuning the structure's natural frequency [8].

Based on their frequent use, the structure of the components of robotic arms must be powerful enough to endure torque and forces acting on them. Choosing the right material for robotics is critical as it directly affects the strength of robotic arms. To explore this question, Jain modelled and analyzed articulated robotic arm utilized in material handling. The design of the gripper was made in SOLIDWORKS® and simulation was done through finite element analysis on ANSYS® software. Different loading conditions and different materials were assigned to the robotic arm to check which material is better for robotic arm. Two materials analyzed in the study were Aluminium and Structural Steel. The results revealed that Structural Steel is better for articulated robotic arm as it produces less deformation as compared to Aluminium [9]. In another study, Mahanta performed analysis for optimal material selection of robot soft finger. Silicone Ecoflex 00-30 was used as the material for robot soft finger [10].

Arunakumara designed and analyzed a robotic arm for automotive industry. They designed the model of robotic arm on SOLIDWORKS® and simulated that model on ANSYS®. Under various loading conditions, the strength, mechanical properties and temperatures were analyzed. Moreover, the stresses associated with different materials were also evaluated and compared [11]. Aluminium alloys are widely used in various industries due to lightweight, high strength and low density [12]. Based on these properties, Ali designed and developed 5 DOF robotic arm using Aluminium for light material handling purposes. The model was developed on SOLIDWORKS® and simulated on ANSYS® at multiple loads. The results of finite element model showed that robotic arm can lift sufficient loads while keeping their structural integrity intact [13]. In another study, Abbasi compared two materials for the development of 5D robotic arm using static structural analysis. The materials analyzed were Aluminium and Poly-methyl methacrylate. Loads in the simulation were varied to observe the behavior of both materials under different loading conditions. The simulation results depicted that Aluminium is better material for development of robotic arm as compared to Poly-methyl methacrylate as deformation associated with Aluminium was less [14].

Daniyan also designed and simulated robotic arm to be used in manufacturing industry based on finite element analysis. The modelling and simulation were carried out in SOLIDWORKS®. Alloy Steel was material was assigned to robotic arm for the simulation. The results showed that under varied loading conditions, the robotic arm won't not fail because negligible strain and displacement were evaluated in the results of finite element analysis [15]. Santosh also performed simulations using finite element analysis on the robotic arm using different materials at various loads. CAD was made on Creo® Parametric and static structural module of ANSYS® was used for the simulation. Two 3D-printing materials were utilized in the study i.e. Polylactic Acid and Acrylonitrile Butadiene Styrene. Moreover, the main support was assigned with Steel. The results demonstrated that Polylactic Acid was better material for the development of robotic arm. Moreover, making the main support of Steel provided even better results [16].

As discussed above, the components of robotic arms are analyzed by different materials being Steel and Aluminium the mostly used materials for robotic arms. Effect of different grades of Steel and Aluminium alloys is still missing. Moreover, no comprehensive financial aspects have been covered in the literature associated with robotic arm components. This research work aims this gap and presents a comprehensive structural and economic comparison of five different grades of Steel alloys (i.e. 304L Stainless Steel, annealed 310 Stainless Steel, annealed 316L Stainless Steel, quenched and tempered 410 Stainless Steel and annealed 446 Stainless Steel) and five different grades of Aluminium alloys (i.e. 5052-H32 Aluminium, 5086—H34 Aluminium, 6061-T8 Aluminium, 6063-T83 Aluminium and 7075-T76 Aluminium) utilized in the connecting rod of articulated robotic arm. The model of connecting rod of articulated robotic arm is designed in SOLIDWORKS® 16.2 and the model is imported in ANSYS® Workbench 19.2. The simulations are done for all the 10 materials in ANSYS® static structural module at varying moment values of 500 Nm, 600 Nm and 700 Nm respectively. Total deformation, Von-Mises stress, equivalent strain and safety factor values are evaluated through simulation. Moreover, the cost required to develop the connecting rod is also evaluated for all alloys using the density and mass. In the end, the materials are compared.

II. MATERIALS AND METHODS

In this study, connecting rod of articulated robotic arm is designed and analyzed with the help of finite element analysis using various Steel and Aluminium alloys. After that cost analysis is also done. The methodology of current study is presented in Figure 1.

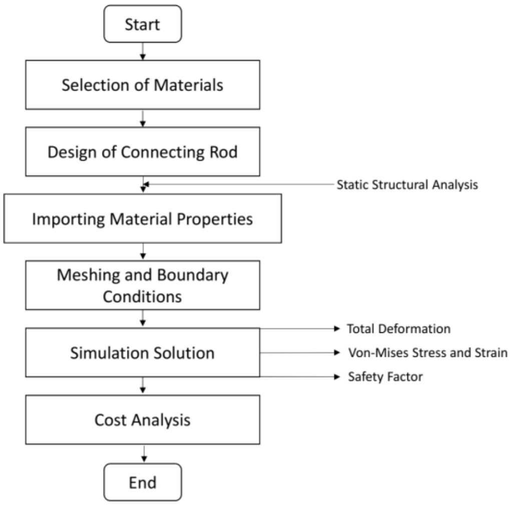

Figure 1: Methodology

TABLE I: Properties of Stainless Steel Alloys and Aluminium Alloy

Material	Density	Ultimate Tensile Strength (MPa)	Yield Tensile Strength (MPa)	Modulus of Elasticity (GPa)	Poisson's Ratio
304L Stainless Steel	7999.5	564	210	195	0.29
310 Stainless Steel (Annealed)	7999.5	655	275	200	0.29
316L Stainless Steel (Annealed)	7999.5	515	205	193	0.29
410 Stainless Steel (Quenched and Tempered)	7805.7	1525	1225	200	0.28
446 Stainless Steel (Annealed)	7805.7	550	345	200	0.27
Aluminium Alloy 5052-H32	2679.4	228	193	70.3	0.33
Aluminium Alloy 5086-H34	2660	324	255	71	0.33
Aluminium Alloy 6061-T8	2698.8	310	276	69	0.33
Aluminium Alloy 6063-T83	2698.8	255	241	68.9	0.33
Aluminium Alloy 7075-T76	2795.7	503	427	71	0.33

The analyzed materials include 304L Stainless Steel, annealed 310 Stainless Steel, annealed 316L Stainless Steel, quenched and tempered 410 Stainless Steel, annealed 446 Stainless Steel, 5052-H32 Aluminium, 5086-H34 Aluminium, 6061-T8 Aluminium, 6063-T83 Aluminium and 7075-T76 Aluminium. This study utilizes a simple connecting rod of articulated robotic arm having the volume of 0.001068653 m^3 whose other dimensions are shown in Figure 2. Moreover, the properties of the aforementioned Steel and Aluminium alloys are taken from internet sources [17-18] and are described in table I. Steel alloys and Aluminium alloys are chosen for study because these two are mostly used materials for robot-making [19] because both have high strength whereas Steel has high corrosion resistance [20].

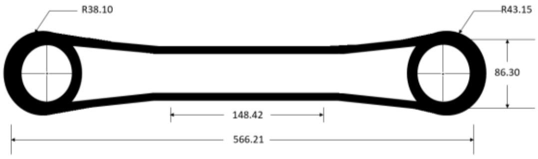

Figure 2: Dimensions of Connecting Rod (mm)

III. MODELING AND SIMULATION

The connecting rod of the articulated robotic arm was designed in the SOLIDWORKS® and geometry is shown in Figure 3. The geometry was exported in IGES format for the compatibility in ANSYS® Workbench 19.2. The properties of alloys were added in the database of ANSYS®. The geometry was imported into the static structural module of ANSYS® Workbench 19.2.

Figure 3: Geometry of Connecting Rod

After that, meshing of the connecting rod was done which divided the connecting rod into finite elements [21-22] using tetrahedral mesh. The meshing elements were 3899 and nodes were 7211. The meshed model of connecting rod is shown in Figure 4.

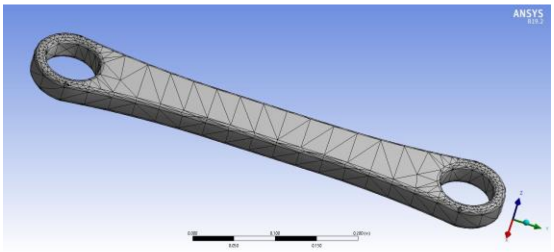

Figure 4: Meshed Geometry of Connecting Rod

The next step after dividing the connecting rod into finite elements was to apply boundary conditions. For this purpose, one end of the connecting rod was given fixed support while on the other end, moment was applied. Moment value was varied in three stages i.e. 500 Nm, 600 Nm and 700 Nm. The boundary conditions of connecting rod are depicted in Figure 5.

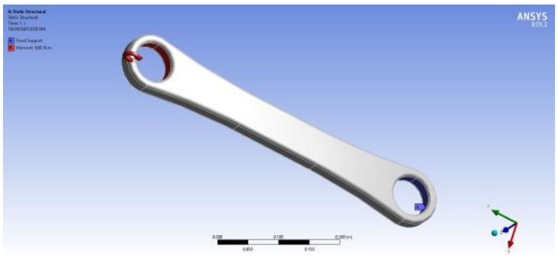

Figure 5: Boundary Conditions Applied to Connecting Rod

After applying the boundary conditions, the model was solved for total deformation, Von-Mises Stress, equivalent strain and safety factor. Initially, all five Stainless Steel alloys were analyzed at the aforementioned moment levels and after that same was done for five Aluminium alloys. Figure 6, 7, 8, 9, 10, 11, 12, 13, 14 and 15 shows total deformations, Von-Mises stresses, equivalent strains and safety factors for 304L Stainless Steel, annealed 310 Stainless Steel, annealed 316L Stainless Steel, quenched and tempered 410 Stainless Steel, annealed 446 Stainless Steel, 5052-H32 Aluminium, 5086-H34 Aluminium, 6061-T8 Aluminium, 6063-T83 Aluminium and 7075-T76 Aluminium respectively.

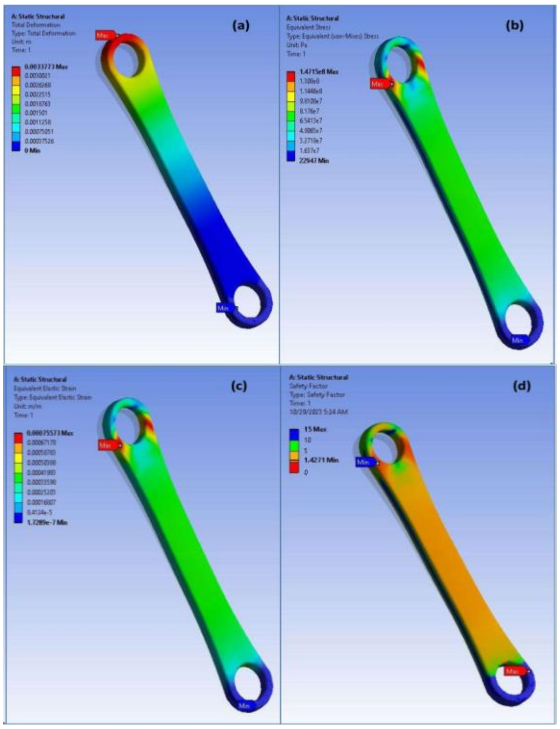

Figure 6: (a) Total Deformation, (b) Von-Mises Stress, (c) Equivalent Strain and (d) Safety Factor of 304L Stainless Steel Alloy at 700 Nm

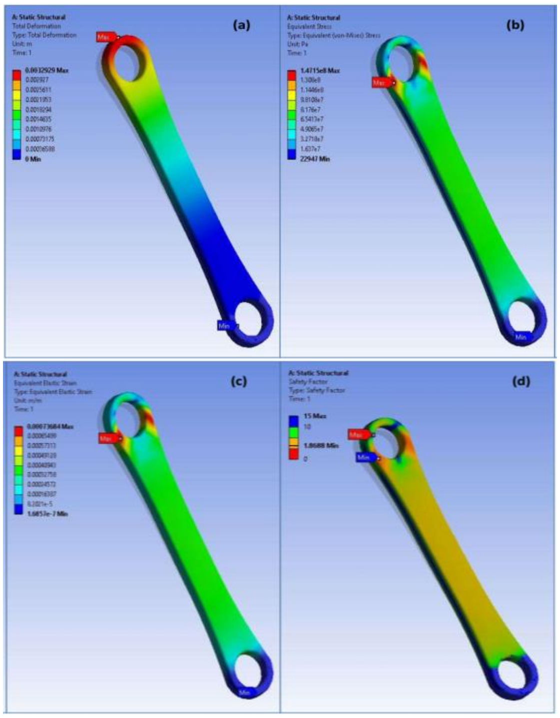

Figure 7: (a) Total Deformation, (b) Von-Mises Stress, (c) Equivalent Strain and (d) Safety Factor of 310 Stainless Steel Alloy (Annealed) at 700 Nm

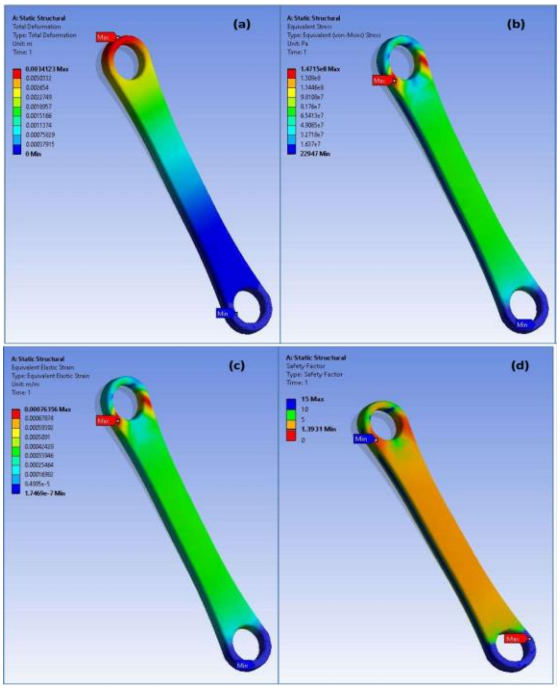

Figure 8: (a) Total Deformation, (b) Von-Mises Stress, (c) Equivalent Strain and (d) Safety Factor of 316L Stainless Steel (Annealed) at 700 Nm

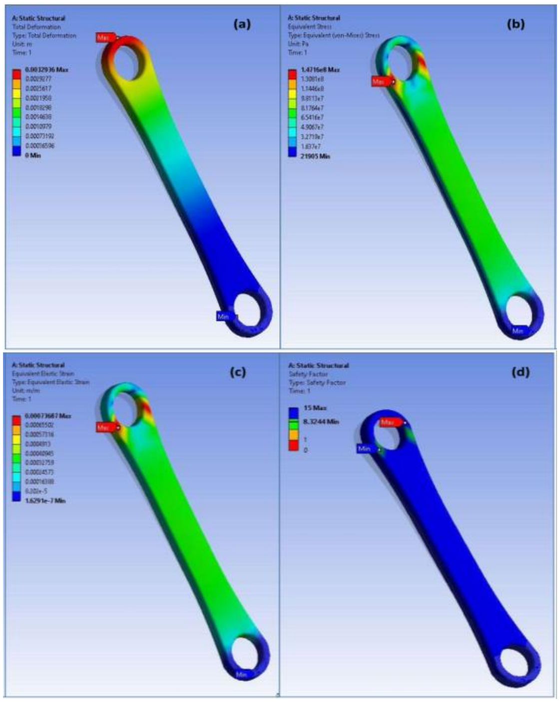

Figure 9: (a) Total Deformation, (b) Von-Mises Stress, (c) Equivalent Strain and (d) Safety Factor of 410 Stainless Steel (Quenched and Tempered) at 700 Nm

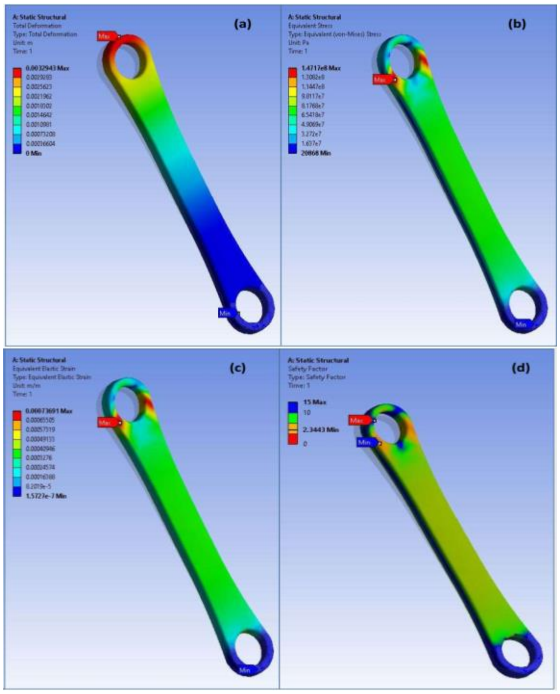

Figure 10: (a) Total Deformation, (b) Von-Mises Stress, (c) Equivalent Strain and (d) Safety Factor of 446 Stainless Steel (Annealed) at 700 Nm

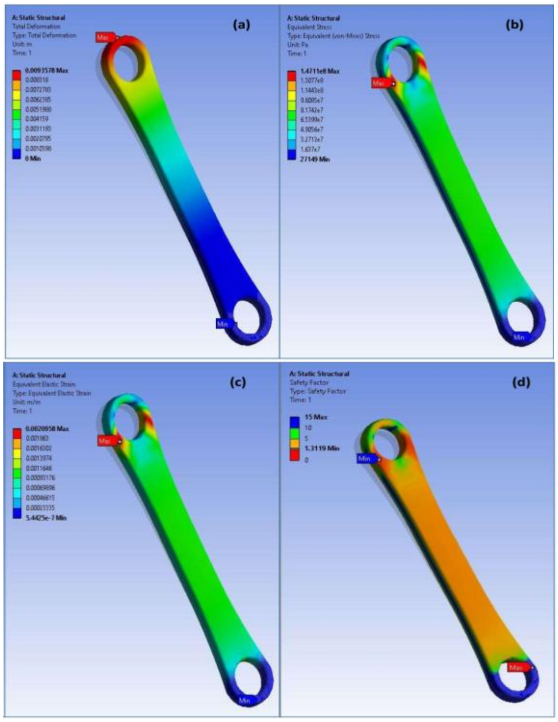

Figure 11: (a) Total Deformation, (b) Von-Mises Stress, (c) Equivalent Strain and (d) Safety Factor of Aluminium Alloy 5052-H32 at 700 Nm

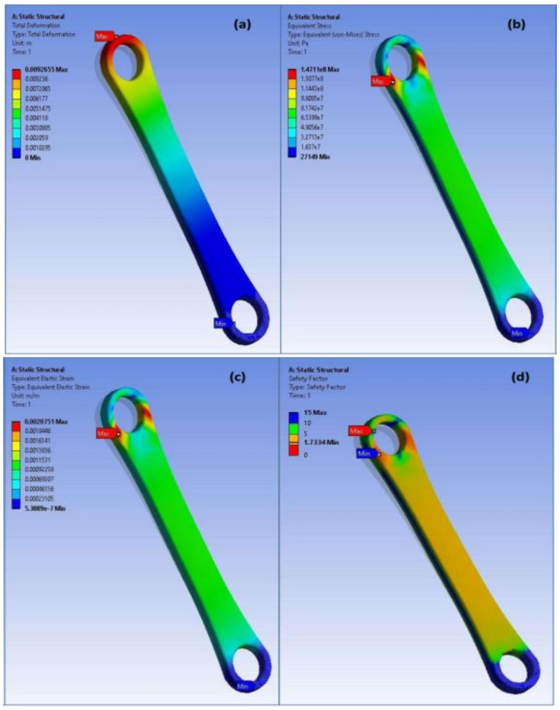

Figure 12: (a) Total Deformation, (b) Von-Mises Stress, (c) Equivalent Strain and (d) Safety Factor of Aluminium Alloy 5086-H34 at 700 Nm

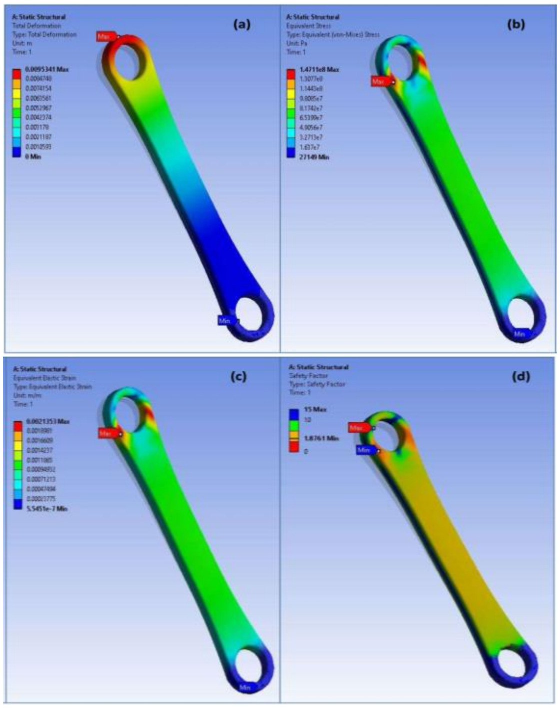

Figure 13: (a) Total Deformation, (b) Von-Mises Stress, (c) Equivalent Strain and (d) Safety Factor of Aluminium Alloy 6061-T8 at 700 Nm

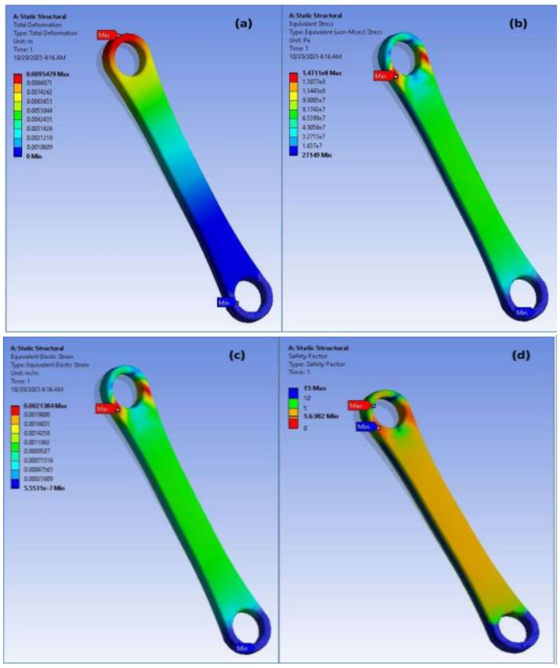

Figure 14: (a) Total Deformation, (b) Von-Mises Stress, (c) Equivalent Strain and (d) Safety Factor of Aluminium Alloy 6063-T83 at 700 Nm

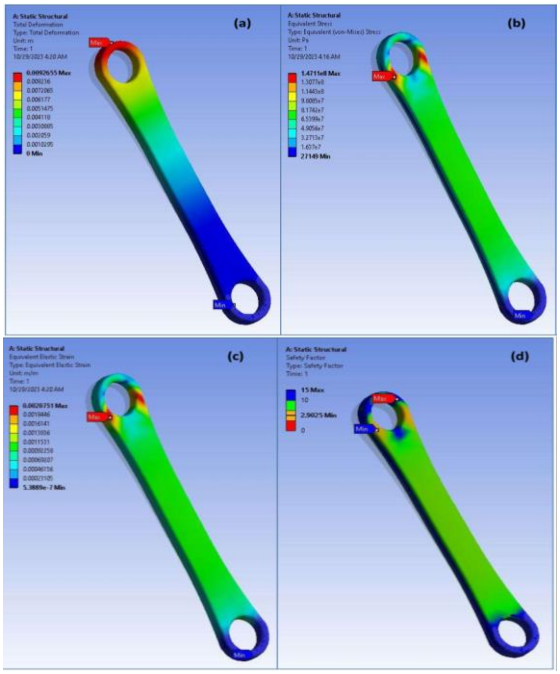

Figure 15: (a) Total Deformation, (b) Von-Mises Stress, (c) Equivalent Strain and (d) Safety Factor of Aluminium Alloy 7075-T76 at 700 Nm

IV. RESULTS AND DISCUSSIONS

4.1 Results of Total Deformation:

After applying boundary conditions, the results of total deformation simulations were obtained. Figure 6 (a), 7 (a), 8 (a), 9 (a), 10 (a), 11 (a), 12 (a), 13 (a), 14 (a) and 15 (a) show the deformed views through output simulation results of total deformation at 700 Nm for 304L Stainless Steel, annealed 310 Stainless Steel, annealed 316L Stainless Steel, quenched and tempered 410 Stainless Steel, annealed 446 Stainless Steel, 5052-H32 Aluminium alloy, 5086—H34 Aluminium alloy, 6061-T8 Aluminium alloy, 6063-T83 Aluminium alloy and 7075-T76 Aluminium alloy respectively.

TABLE II: Results of Total Deformation

Total Deformation (mm)			
Material	**500 Nm**	**600 Nm**	**700 Nm**
304L Stainless Steel	2.4124	2.8948	3.3773
310 Stainless Steel (Annealed)	2.3521	2.8225	3.2929
316L Stainless Steel (Annealed)	2.4374	2.9248	3.4123
410 Stainless Steel (Quenched and Tempered)	2.3526	2.8231	3.2936
446 Stainless Steel (Annealed)	2.3531	2.8237	3.2943
Aluminium Alloy 5052-H32	6.6841	8.021	9.3578
Aluminium Alloy 5086-H34	6.6182	7.9419	9.2655
Aluminium Alloy 6061-T8	6.8101	8.1721	9.5341
Aluminium Alloy 6063-T83	6.82	8.184	9.5479
Aluminium Alloy 7075-T76	6.6182	7.9419	9.2655

The results show that Stainless Steel alloys have less experienced less deformation when subjected to variable moment values. Figure 16 and Figure 17 show that Aluminium alloys have more deformation at the same values of moment. Apart from it, an increase in total deformation was observed with increasing moment value for all the alloys. The collective results of total deformation are tabulated in table II.

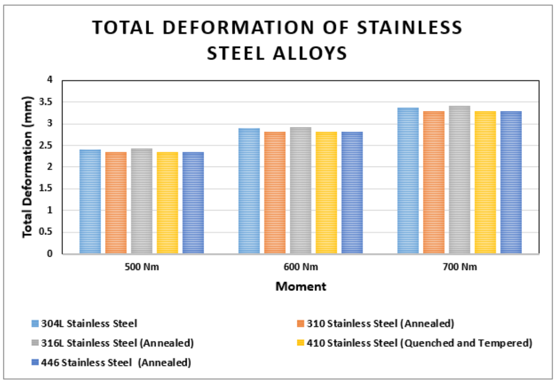

Figure 16: Total Deformation of Connecting Rod made of Stainless Steel Alloys

Among Steel alloys, lowest deformation was recorded in 310 Stainless Steel alloy (annealed) whereas maximum deformation value was recorded in the case of 316L Stainless Steel. For Aluminium, lowest deformation was recorded in Aluminium 5086-H34 and Aluminium 7075-T76 whereas highest deformation was recorded in Aluminium 5052-H34 alloy.

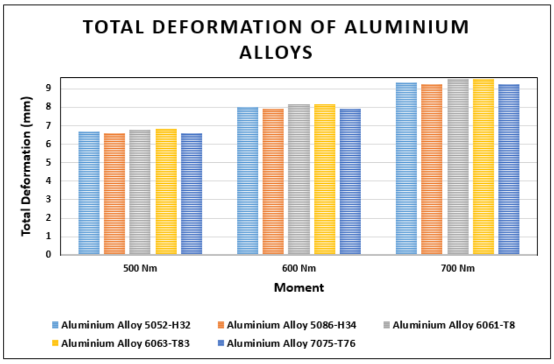

Figure 17: Total Deformation of Connecting Rod made of Aluminium Alloys

4.2 Results of Von-Mises Stress:

Figures 6 (b), 7 (b), 8 (b), 9 (b), 10 (b), 11 (b), 12 (b), 13 (b), 14 (b) and 15 (b) show the von-Mises stress output results at 700 Nm for 304L Stainless Steel, annealed 310 Stainless Steel, annealed 316L Stainless Steel, quenched and tempered 410 Stainless Steel, annealed 446 Stainless Steel, 5052-H32 Aluminium alloy, 5086—H34 Aluminium alloy, 6061-T8 Aluminium alloy, 6063-T83 Aluminium alloy and 7075-T76 Aluminium alloy respectively. Table III shows the results of von-Mises stress for all the analyzed alloys. From the table it can be seen that Stainless Steel alloys have almost same values whereas Aluminium alloys also have the same values for von-Mises stress as the major alloying elements and some of the properties like Poisson's ratio, density, etc. are similar. Moreover, a linear increasing trend of von-Mises stress values with respect to increasing moment was observed.

TABLE III: Results of Von-Mises Stress

Equivalent Stress (MPa)			
Material	**500 Nm**	**600 Nm**	**700 Nm**
304L Stainless Steel	105.110000	126.130000	147.150000
310 Stainless Steel (Annealed)	105.110000	126.130000	147.150000
316L Stainless Steel (Annealed)	105.110000	126.130000	147.150000
410 Stainless Steel (Quenched and Tempered)	105.110000	126.140000	147.160000
446 Stainless Steel (Annealed)	105.120000	126.140000	147.170000
Aluminium Alloy 5052-H32	105.080000	126.100000	147.110000
Aluminium Alloy 5086-H34	105.080000	126.100000	147.110000
Aluminium Alloy 6061-T8	105.080000	126.100000	147.110000
Aluminium Alloy 6063-T83	105.080000	126.100000	147.110000
Aluminium Alloy 7075-T76	105.080000	126.100000	147.110000

4.3 Results of Equivalent Strain:

After von-Mises stress, equivalent strain of the connecting rod was also simulated. Simulation results of connecting rod for articulated robotic arm for equivalent strain at 700 Nm moment are shown in Figures 6 (c), 7 (c), 8 (c), 9 (c), 10 (c), 11 (c), 12 (c), 13 (c), 14 (c) and 15 (c) for 304L Stainless Steel, annealed 310 Stainless Steel, annealed 316L Stainless Steel, quenched and tempered 410 Stainless Steel, annealed 446 Stainless Steel, 5052-H32 Aluminium alloy, 5086—H34 Aluminium alloy, 6061-T8 Aluminium alloy, 6063-T83 Aluminium alloy and 7075-T76 Aluminium alloy respectively.

TABLE IV: Results of Equivalent Strain

Equivalent Strain (m/m)			
Material	**500 Nm**	**600 Nm**	**700 Nm**
304L Stainless Steel	5.40E-04	6.48E-04	7.56E-04
310 Stainless Steel (Annealed)	5.26E-04	6.32E-04	7.37E-04
316L Stainless Steel (Annealed)	5.45E-04	6.54E-04	7.64E-04
410 Stainless Steel (Quenched and Tempered)	5.26E-04	6.32E-04	7.37E-04
446 Stainless Steel (Annealed)	5.26E-04	6.32E-04	7.37E-04
Aluminium Alloy 5052-H32	1.50E-03	1.80E-03	2.10E-03
Aluminium Alloy 5086-H34	1.48E-03	1.78E-03	2.08E-03
Aluminium Alloy 6061-T8	1.53E-03	1.83E-03	2.14E-03
Aluminium Alloy 6063-T83	1.53E-03	1.83E-03	2.14E-03
Aluminium Alloy 7075-T76	1.48E-03	1.78E-03	2.08E-03

ISSN:1813-1786 (Print) 2313-7770 (Online)

The results showed a linear increase in equivalent strain of all he alloys with increasing moment. The results of equivalent strain for all the alloys at all loading conditions are presented in table IV.

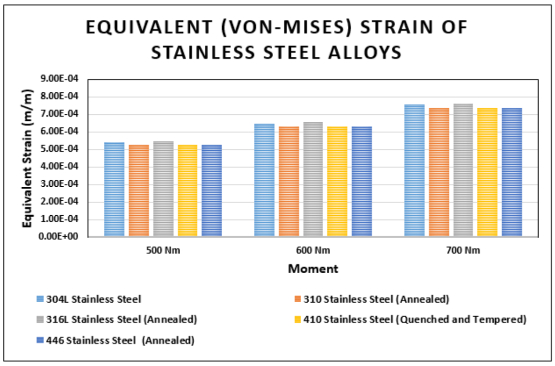

Figure 18: Equivalent Strain of Connecting Rod made of Stainless Steel Alloys

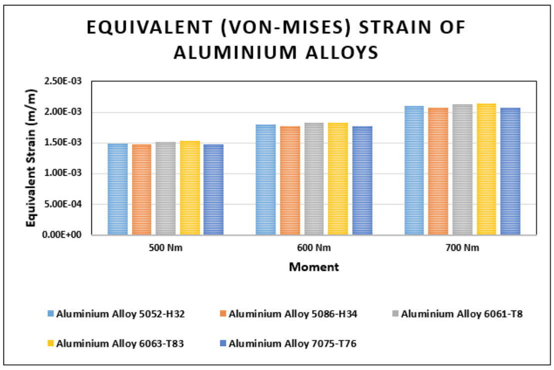

Figure 19: Equivalent Strain of Connecting Rod made of Aluminium Alloys

From Figure 18, it can be shown that 310 Stainless Steel has the lowest strain value whereas 316L Stainless Steel has the highest strain value at all moment values. Whereas Figure 19 depicts that 5086-H34 Aluminium alloy and 7075-T76 Aluminium alloy have the lowest values of equivalent strain whereas 6063-T83 has the highest value of equivalent strain.

4.4 Results of Safety Factor:

Safety factor results were also simulated using stress tool in static structural analysis of ANSYS® Workbench 19.2. for safety factor, minimum values were observed. Figures 6 (d), 7 (d), 8 (d), 9 (d), 10 (d), 11 (d), 12 (d), 13 (d), 14 (d) and 15 (d) show safety factor results at 700 Nm moment for 304L Stainless Steel, annealed 310 Stainless Steel, annealed 316L Stainless Steel, quenched and tempered 410 Stainless Steel, annealed 446 Stainless Steel, 5052-H32 Aluminium alloy, 5086—H34 Aluminium alloy, 6061-T8 Aluminium alloy, 6063-T83 Aluminium alloy and 7075-T76 Aluminium alloy respectively.

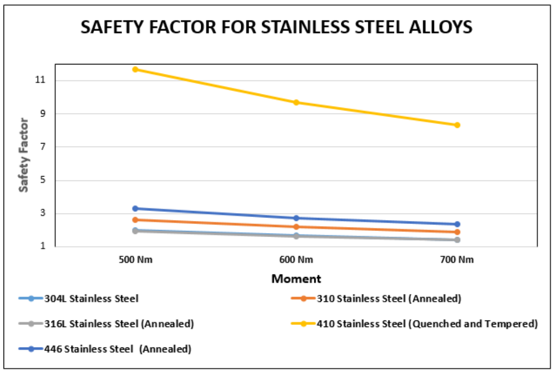

Figure 20: Safety Factor of Connecting Rod made of Stainless Steel Alloys

Figure 20 shows that 410 Stainless Steel (quenched and tempered) shows the highest safety factor among all Stainless Steel alloys for all moment values. 446 Stainless Steel is on the second rank whereas 310 Stainless Steel is on third rank. 316L Stainless Steel has the lowest safety factor value.

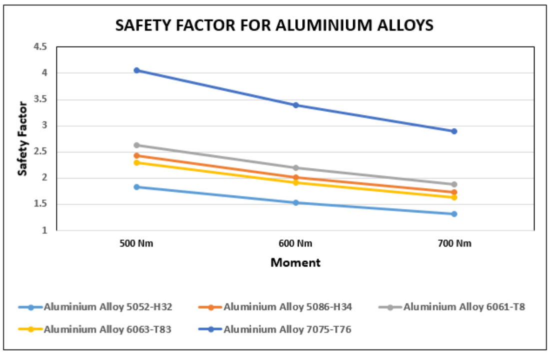

Figure 21: Safety Factor of Connecting Rod made of Aluminium Alloys

Figure 21 shows the graph of safety factor for Aluminium alloys. It can be observed that 7075-T76 Aluminium alloy has the maximum safety factor values among all the analyzed moment values,

TABLE V: Results of Safety Factor

Safety Factor			
Material	**500 Nm**	**600 Nm**	**700 Nm**
304L Stainless Steel	1.998	1.665	1.4271
310 Stainless Steel (Annealed)	2.6164	2.1803	1.8688
316L Stainless Steel (Annealed)	1.9504	1.6253	1.3931
410 Stainless Steel (Quenched and Tempered)	11.654	9.7118	8.3244
446 Stainless Steel (Annealed)	3.282	2.735	2.3443
Aluminium Alloy 5052-H32	1.8367	1.5306	1.3119
Aluminium Alloy 5086-H34	2.4267	2.0222	1.7334
Aluminium Alloy 6061-T8	2.6265	2.1888	1.8761
Aluminium Alloy 6063-T83	2.2935	1.9112	1.6382
Aluminium Alloy 7075-T76	4.0635	3.3863	2.9025

Whereas 5052-H32 has the lowest safety factor. The results of safety factors are shown in table V.

4.5 Cost Analysis:

Cost analysis of the analyzed connecting rod was done on Microsoft® Excel. The prices of materials were taken from internet sources [23-24]. The prices were converted into dollars. And the mass required to develop this connecting rod was calculated through the volume i.e. 0.001068653 m^3 and density of the materials. The mass in kilograms was then multiplied by the price per kg to calculate the cost required to prepare the connecting rod of articulated robotic arm.

Figure 22 shows the cost of connecting rod for different materials whereas table VI shows the cost analysis.

TABLE VI: Cost Analysis of Different Materials for Connecting Rod

Material	Density in kg/m^3 (ρ)	Volume of Connecting Rod under Analysis in m^3 (V)	Mass Required to produce Connecting Rod in kg (ρxV)	Price of Material per kg*	Cost of Material to produce Connecting Rod
304L Stainless Steel	7999.5	0.001068653	8.548690219	$ 2.22	$ 18.98
310 Stainless Steel	7999.5	0.001068653	8.548690219	$ 2.40	$ 20.52
316L Stainless Steel	7999.5	0.001068653	8.548690219	$ 2.88	$ 24.62
410 Stainless Steel	7805.7	0.001068653	8.341585255	$ 4.26	$ 35.54
446 Stainless Steel	7805.7	0.001068653	8.341585255	$ 4.32	$ 36.04
5052 Aluminium Alloy	2679.4	0.001068653	2.863349031	$ 4.80	$ 13.74
5086 Aluminium Alloy	2660	0.001068653	2.842617162	$ 3.60	$ 10.23
6061 Aluminium Alloy	2698.8	0.001068653	2.884080901	$ 4.08	$ 11.77
6063 Aluminium Alloy	2698.8	0.001068653	2.884080901	$ 3.90	$ 11.25
7075 Aluminium Alloy	2795.7	0.001068653	2.987633383	$ 79	$ 23.27

*As of October 29, 2023

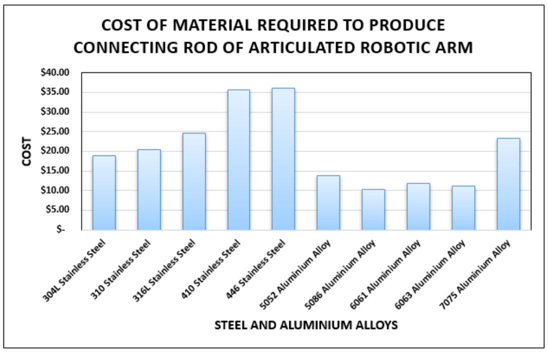

Figure 22: Cost Required to produce Connecting Rod of Articulated Robotic Arm using Different Materials

The results of cost analysis show that among all the alloys, 5086 Aluminium alloy is the most economical material for production of connecting rod of an articulated robotic arm. Among Steels, 310 Stainless Steel is economical whereas 446 Stainless steel is expensive. Talking about Aluminium alloys, 5086 Aluminium alloy is more economical whereas 7075 Aluminium alloy is expensive for the production of analyzed connecting rod.

4.6 Comparison among Stainless Steel and Aluminium Alloys:

Overall, Steels showed prominent results of simulation as compared to Aluminium alloys. Aluminium alloys show more deformation and strain. Whereas safety factor in case of Aluminium alloys is also more than that of Stainless Steel alloys. As thermal conductivity of Aluminium alloys is higher than that of Steel alloys, higher temperature would affect the Aluminium alloys more than Steel alloys [25]. In terms of financial aspects, Aluminium alloys are economical but they show less promising results. 410 Stainless Steel and 7075 Aluminium alloy have good values of safety factor but their cost is exponentially higher than other. Among all the materials, 310 Stainless Steel can be a promising material for the production of connecting rod. Table VI shows the cost analysis of connecting rod made with different Steel and Aluminium alloys.

V. CONCLUSION

Structural analysis of connecting rod for an articulated robotic arm and cost analysis has been done in this study. Five Stainless Steel alloys and five Aluminium alloys have been used in the simulation of connecting rod. Effect of materials and effect of moment values on the strength of the connecting rod are presented. Moreover, cost of material that is required to manufacture the analyzed connecting rod is also determined for each material. The conclusions of this research work are discussed below:

- Both Stainless Steel alloys and Aluminium alloys can be used in the manufacturing of articulated robotic arm parts.
- Stainless Steel alloys provide better results in terms of deformation and equivalent strain values.
- The cost of material required to make connecting rod of articulated robotic arm using Aluminium alloy is comparatively less than that of Stainless Steel alloys but chances of deformation are more in this case.
- 5086 Aluminium alloy is most economical alloy for the production of connecting rod but its deformation is significantly higher than Stainless Steel alloys.
- The results of deformation, stress and strain of 304L Stainless Steel are promising and similar

to that of 310 Stainless Steel but safety factor is less as compared to 310 Stainless Steel.

- Total deformation, von-Mises stress and equivalent strain increase as the value of moment increase irrespective of the material.
- Safety factor values show decreasing trend with an increase in moment value.
- 310 Stainless Steel is the best possible choice for the manufacturing of articulated robotic arm parts as it shows promising results in simulation as well as its cost is comparatively less than other analyzed Stainless Steel alloys. Moreover, its safety factor is ranked at third position which is still sufficiently good.

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