

Improving the Mechanical Properties of Conventional Materials by Nano-Coating, Part-1

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Abstract

The use of an advanced nanotechnology coating process is absolutely helpful in immensely optimizing the efficiency of mechanical properties of materials such as: Longer service life, ability to tolerate greater loads, ease and low cost of maintenance, the environmental gain in the conservation of resources, improved response in kinetic systems, lower energy consumption, resistance to corrosion, low friction, use of low-cost base material, etc. Metal materials are usually subjected to various surface conditions that might cause stress, strain, deformation, and corrosion. Accordingly, Nano-coating technology is used to enhance the performance of mechanical properties in addition to reduce mechanical failure as much as possible. This research, a simulation of Nano coating effect on some mechanical properties performance using Finite Element Analysis (FEA) software was carried out. The prime focus here was on exposing a thin Aluminum (Al7075-T6) walled spherical vessel to internal pressure before and after coating, this spherical vessel was coated by nano-layer using two different materials such as Titanium (Ti) and Nickel (Ni) with thicknesses ranging (100nm, 500nm, and 900nm). Then a comparison of the obtained results was made before and after coating, the results showed that the aluminum 7075-T6 thin walled spherical vessel was successfully coated with Titanium and Nickel separately using ANSYS software. Also the results showed that 900nm Nickel coated aluminum 7075-T6 thin walled spherical vessel has a better improvement in mechanical properties. These improvements in mechanical properties were varied between 4.5225% to 20.724% depending on coating thickness and coating material. The Nickel coating has shown higher improvements in comparison with Titanium were observed.

Keywords: Mechanical Properties, Nano, Coating, Ti, Ni, and AL 70705-T₆

List of Abbreviations

Al: Aluminum, ASM: American Society for Metals, FEA: Finite Element Analysis, GPT: General Purpose Technology, Ni : Nickel, PAS: Publicly Available Specification, Ti: Titanium, nm : nanometer, ϵ_c : the circumferential strain, ϵ_r : radial strain, ϵ_t : tangential strain , P : Resultant Pressure Force, P : Pascal , r: radius of the sphere , t: thickness, σ : sigma (tensile stresses), E : Modulus of elasticity , p: Fluid Pressure, ν : Poisson ratio

Background

Nanotechnology is a nascent, vibrant, and burgeoning scientific discipline that is predicted to have important implications for an extraordinarily broad array of applications encompassing almost every industrial sector. It is surmised that virtually no facet of the industry will be left uninfluenced by its seemingly ubiquitous reach. Nanotechnology is defined as the capacity for the controllable manipulation of matter at the molecular and atomic levels, typically from 1 nm to 100 nm. It allows for and encompasses the fundamental ability to synthesize novel materials and to create devices that exhibit extraordinary properties with enhanced functionality. One compelling driver of this technology lies in

the premise that matter behaves in radically different ways for nanoscale materials in contrast to their bulk material counterparts. Nanoscale materials can possess innumerable components that are endowed with exponentially greater surface areas, which are critical in many industrial processes. Nanomaterials or Nanoscale materials are defined as a set of substances where at least one dimension is less than approximately 100 nanometers. A nanometer is one millionth of a millimeter - approximately 100,000 times smaller than the diameter of a human hair as shown in figure-1. Nanomaterials are of interest because at this scale unique optical, magnetic, electrical, and other properties emerge. These emergent properties have the potential for great impacts in electronics, medicine, and other fields. (A, Alagarasi, 2011). Nano coatings have the potential for enhancing the performance and durability of an extensive array of manufacturing processes, in addition to improving the items that they produce. They may thus enable significant energy savings to be realized across just about every market sector. Nano coating imparts multifunctional attributes to many everyday consumer and industrial products.



Figure 1: Nano-material (National Center for Electron Microscopy, Lawrence Berkeley Lab, US. Department of Energy)

Nanotechnology

Richard Feynman gave flight to the concept of nanotechnology via his 1959 introductory lecture "There's Plenty of Room at the Bottom." Sited in 1986 K. Eric Drexler's book *Engines of Creation* articulated the promise of this new science in the diverse range of future scenarios. An important development that transitioned many "Nano visions" into tangible reality was the development of Scanning Tunneling Microscopy (1981) and Atomic Force Microscopy (1986). These instruments enabled imaging at a Nano metric resolution and the manipulation of individual atoms. (Boehm, Frank. 2010) Nanotechnology is a newly emerging branch of technology, which incur high expectations of its possibility to change the world fundamentally. Some policymakers and technology developers even speak about "the Next Industrial Revolution", which advancing nanotechnology is supposed to bring along (Schummer, 2004). Others argue that nanotechnology is just a new label put on research projects in conventional fields of science – such as chemistry, physics, biomedical engineering, materials science and electrical engineering to gain more research funding. However, there have been also efforts to define various terms in the field of nanotechnology, and thus build a common understanding about the issue.

Research objectives

The main objectives of this work are:

Studying and analyzing the mechanical properties improvement when using a Nano coating of Al 7075-T6 alloy. The following stresses will be studied and analyzed includes, which are:

- Normal Stresses in X and Y axis.
- Shear Stresses in XY and XZ plane.
- Equivalent (Von-Misses) stresses
- Studying and analyzing normal elastic strain in X and Y axis
- Studying and analyzing total deformation

Research Methodology

In this work a simulation of the Nano coating effect on mechanical properties for optimizing its performance using FEA software were carried out. The prime focus here was on exposing a thin walled spherical vessel made of Aluminum (Al7075-T6) under internal pressure before and after coating with Nano coated materials such as Titanium (Ti) and Nickel (Ni) with different thicknesses. A comparison of the results before and after coating will be made. In the same fashion prepared electro-deposition of composite coatings containing Nano particles in a metal matrix. It was showed that the inclusion of Nano sized particles can give rise to increased micro hardness and corrosion resistance and modified growth to form a Nano crystalline metal deposit and shifted reduction potential of a metal ion. (Low et al, 2006). The above observations motivated the present investigation, where an attempt will be made to develop and characterize the mechanical, chemical properties, micro structural and compositional features of the coating in present work.

Theoretical Analysis

The proposed work as a comparison of the performance analysis of mechanical properties of Nano coated and uncoated for the Al7075-T6 alloy. The work will be intend to enhance the mechanical properties, life time, ability of carrying high stress and the resistance to deformation of aluminum alloy AL 7075-T6. The finite element analysis (FEA) will be performed on thin walled spherical pressure vessels geometry under internal pressure compared with the uncoated and coated with Nano thicknesses of Titanium and Nickel separately by using surface coating function in ANSYS software (Products Release 19.0).

Pressure Vessel

Pressure vessel is a tank contains pressures, either internal or external. This pressure may be obtained from an external source, or by the application of heat from a direct or indirect source, or any combination thereof. (Boiler, ASME and Code, P.V.1989). Spherical shells as structural parts are used extensively in many applications, like nuclear, offshore, fossil oil and transport, because they can be subjected to variable loading conditions like external pressures or internal or both (V. Prasad and B. Praveen Kumar, 2017) for the following advantages:

- The stress resistance considered to be uniform
- The distribution of pressure is uniform upon the tank storage.

- Sphere contains more volume for the surface area.
- Also metal thickness is sometimes about half as much as a cylinder of the same diameter for the same pressure rating.
- The stresses and strains are spreading more uniformly.
- The cost of the wall thickness of a spherical shell will be about half the wall thickness needed for acylindrical shell for holding in the same pressure. So, in a spherical container use a thinner shell which means lesser cost and weight.
- Area to volume ratio is the area that a sphere occupies will be lesser compared to a cylindrical container of the same volume.

But in spite of the above advantages spherical pressure vessels are more expensive than cylindrical pressure vessels to fabricate, and this higher price is only justifiable for large vessels.

The Geometric Modeling of the Case Study

One finite element model is created, it is a thin walled spherical pressure vessel coated with different Nano thickness of Titanium and Nickel separately. As seen in figures (2 to 5).

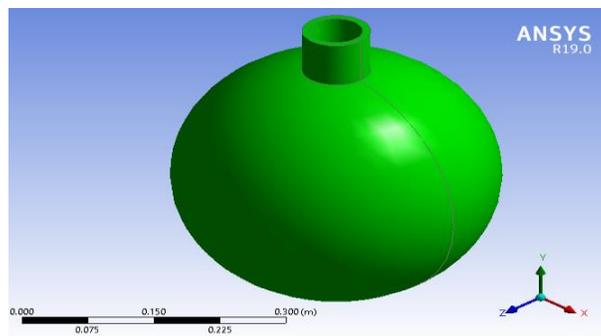


Figure 2: 3D Thin walled Spherical vessel

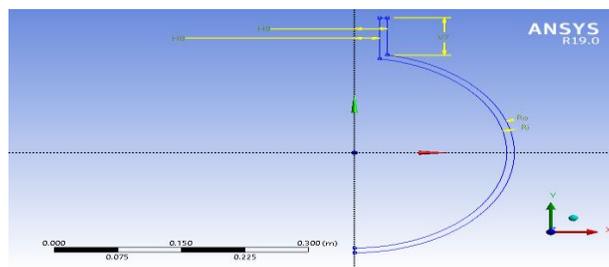


Figure 3: Front view thin Spherical Vessel with Dimensions

Where: $H_8 = 0.03$ m, $H_9 = 0.039$ m, $R_i = 0.18$ m, $R_o = 0.189$ m, $V_7 = 0.07$ m

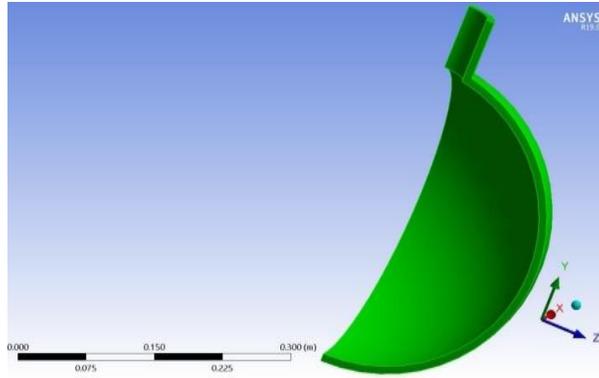


Figure 4: 90° Thin walled Spherical vessel

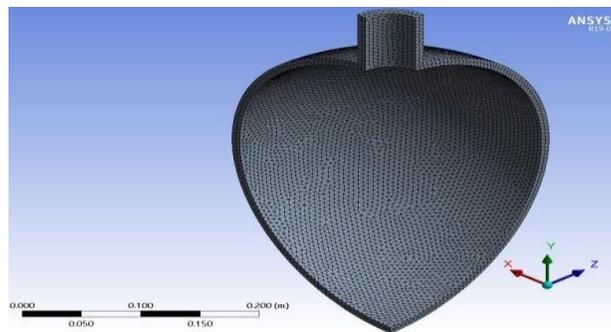


Figure 5: 90° Thin walled spherical vessel with 5 mm elements size of mesh

Stress Analysis in the thin-Walled Spherical Pressure Vessel

Theoretically, spherical shape it is the ideal shape for a vessel that resists internal pressure. To derive the stresses in a spherical vessel, a cut through the sphere on a vertical diametric plane as in Fig. 6a and isolate half of the shell and its fluid contents as a single free body (Fig. 6b), was made acting on this free body is the tensile stresses σ in the wall of the vessel and the fluid pressure p . This pressure acts horizontally against the plane circular area of fluid remaining inside the hemisphere. Since the pressure is uniform, the resultant pressure force P as in Fig. 6b (Gere and Goodno, 2008)

$$P = p(\pi r^2) \tag{1}$$

Where, r : is the inner radius of the sphere, p : net internal pressure, or the gage pressure. Because of the symmetry of the vessel and its loading (Fig. 6b), the tensile stress σ is uniform around the circumference. Moreover, since the wall is thin, an assumption with good accuracy may be used in which the stress is uniformly distributed across the thickness t . The accuracy of this approximation rise as the shell becomes thinner and lowers as it becomes thicker. The resultant of the tensile stresses σ in the wall is a horizontal force equal to the stress σ times the area over which it acts, or

$$\sigma(2\pi r_m t) \tag{2}$$

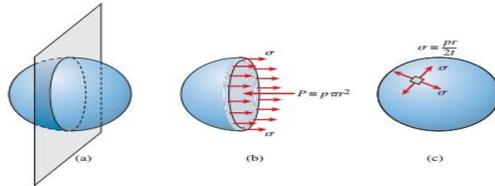


Figure 6: Tensile stresses σ in the Wall of a Spherical Pressure Vessel (Gere and Goodno, 2008)

Where, t : the thickness of the wall, r_m : It's the mean radius where, $r_m = r + \frac{t}{2}$ (3)

Thus, equilibrium of forces in the horizontal direction (Fig. 6b) gives $\sum F_{horiz} = 0$ $\sigma(2\pi r_m t) - p(\pi r^2) = 0$ (4)

Will get the tensile stresses in the wall of the vessel

$$\sigma = \frac{pr^2}{2r_m t} \quad (5)$$

This analysis is valid only for thin shells, disregarding the small difference between the two radii appearing in equation (4) and replace r by r_m or replace r_m by r . While either choice is satisfactory for this approximate analysis, it turns out that the stresses are closer to the theoretically exact stresses if using the inner radius r instead of the mean radius r_m . Therefore, will adopt the following formula for calculating the tensile stresses in the wall of a spherical shell:

$$\sigma = \frac{pr}{2t} \quad (6)$$

As is evident from the symmetry of a spherical shell, it will obtain the same equation for the tensile stresses when cutting a plane through the center of the sphere in any direction. So, we have the following conclusion: The wall of a pressurized spherical vessel is subjected to uniform tensile stresses σ in all directions. This stress condition is represented in Fig. 6c, by the small stress element with stresses σ acting in mutually perpendicular directions (Gere and Goodno, 2008). Because of the symmetry of the sphere and of the pressure loading, the circumferential (or tangential or hoop) stress at any location and in any tangential orientation must be the same and there will be zero Shear Stresses. (Kelly, P., 2013).

Strain Analysis of the Thin-Walled Spherical Pressure Vessel

The thin-walled pressure vessel will extend when it is internally pressurized. These results in three principal strains, the circumferential strain ϵ_c (or tangential strain ϵ_t) in two perpendicular in-plane directions, and the radial strain ϵ_r . referring to Fig. (7), these strains are:

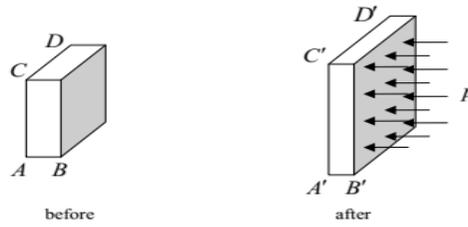


Figure 7: Strain of an Element at the Surface of a Spherical Pressure Vessel (Kelly, P., 2013).

$$\epsilon_c = \frac{A'C' - AC}{AC} = \frac{C'D' - CD}{CD}, \epsilon_r = \frac{A'B' - AB}{AB} \quad (7)$$

$$\epsilon_{xx} = \frac{1}{E} [\sigma_{xx} - \nu(\sigma_{yy} + \sigma_{zz})] \quad (8)$$

$$\epsilon_{yy} = \frac{1}{E} [\sigma_{yy} - \nu(\sigma_{xx} + \sigma_{zz})] \quad (9)$$

$$\epsilon_{zz} = \frac{1}{E} [\sigma_{zz} - \nu(\sigma_{xx} + \sigma_{yy})] \quad (10)$$

$$\epsilon_{xy} = \frac{1+\nu}{E} \sigma_{xy} \quad (11)$$

$$\epsilon_{xz} = \frac{1+\nu}{E} \sigma_{xz} \quad (12)$$

$$\epsilon_{yz} = \frac{1+\nu}{E} \sigma_{yz} \quad (13)$$

From Hooke's law (equations: 8- 13) with z the radial direction, with $\sigma_r=0$:

$$\begin{bmatrix} \epsilon_c \\ \epsilon_c \\ \epsilon_r \end{bmatrix} = \begin{bmatrix} 1/E & -\nu/E & -\nu/E \\ -\nu/E & 1/E & -\nu/E \\ -\nu/E & -\nu/E & 1/E \end{bmatrix} \begin{bmatrix} \sigma_t \\ \sigma_t \\ \sigma_t \end{bmatrix} = \frac{1}{E} \frac{pr}{2t} \begin{bmatrix} 1 - \nu \\ 1 - \nu \\ 1 - \nu \end{bmatrix} \quad (14)$$

Equations (7 to 14) are from (Kelly, P., 2013). To calculate the amount by which the vessel expands, consider a circumference at average radius r which moves out with a displacement δr , Fig.8. From the definition of normal strain

$$\epsilon_c = \frac{(r+\delta_r)\Delta\theta - r\Delta\theta}{r\Delta\theta} = \frac{\delta r}{r} \quad (15)$$

This is the circumferential strain for points on the mid-radius. The strain at other points in the vessel can be approximated by this value.

The expansion of the sphere is thus

$$\delta_r = r\epsilon_c = \frac{1-\nu pr^2}{E 2t} \quad (16)$$

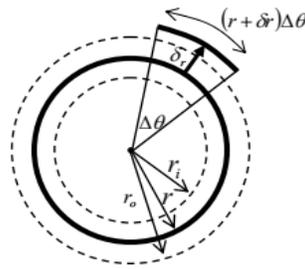


Figure 8: Deformation in the thin-walled Sphere as it Expands (Kelly, P., 2013).

To determine the amount by which the circumference increases in size, consider Fig. 9, which shows the original circumference at radius r of length c increase in size by an amount δ_c . One has

$$\delta_c = c \epsilon_c = 2\pi r \epsilon_c = 2\pi \frac{1-\nu}{E} \frac{pr^2}{2t} \quad (17)$$

It follows from equations (16 and 17) that the circumference and radius increases are related through. (Kelly, P., 2013).

$$\delta_c = 2\pi \delta_r \quad (18)$$

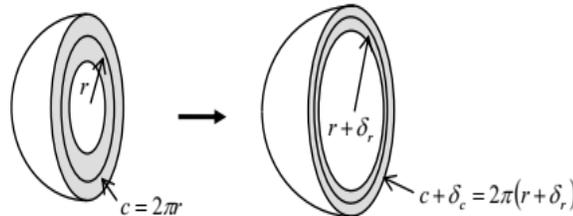


Figure 9: Increase in Circumference Length as the Vessel Expands (Kelly, P., 2013).

Results and Discussions

The improvement in mechanical properties such as , lifetime, ability of carrying high stress and the resistance to deformation, done on aluminum alloy (Al 7075-T6) as a thin-walled spherical vessel, coated with different Nano thicknesses of Titanium (Ti) and Nickel (Ni) using surface coating technique in ANSYS Software, Product Release 19.0. This work began by applying internal pressure (1 bar) to a thin-walled spherical vessel made from (Al 7075-T6) without coating and finding the effects on mechanical properties, after which the internal pressure value was kept at (1 bar) and surfaces coating was applied in the range of (100nm,500nm and 900nm) thicknesses of a Titanium and Nickel separately, these mechanical properties at each stage, as follows:

a) Total Deformation: Total Deformation used to obtain displacements due to internal pressure (stress) in X, Y, and Z directions, figures (10 to 16), and table (1) show the value of the improvement in Total Deformation in thin-walled spherical pressure vessel, before and after coating with different Nano thicknesses of Titanium and Nickel separately.

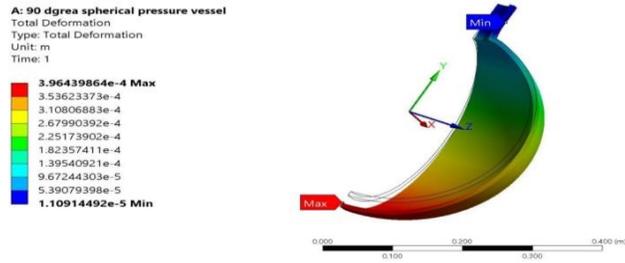


Figure 10: Total Deformation of Al7075-T6 without coating

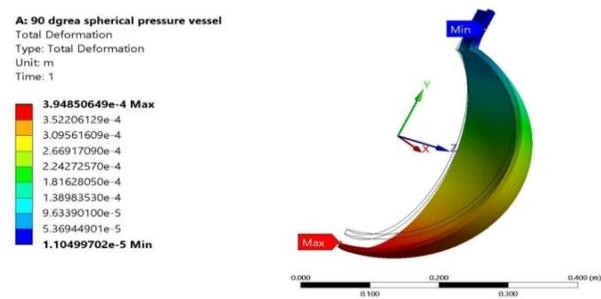


Figure 11: Total Deformation of Al7075-T6 with 100 Nanometers of Titanium

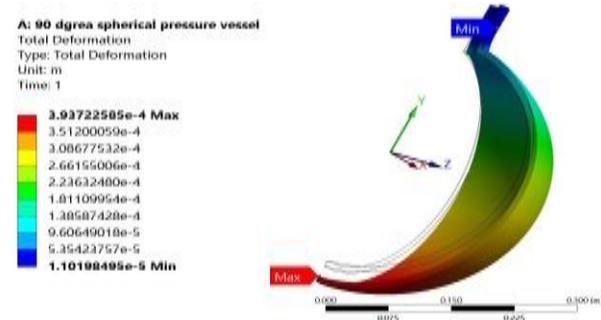


Figure 12: Total Deformation of Al7075-T6 with 100 Nanometers of Nickel.

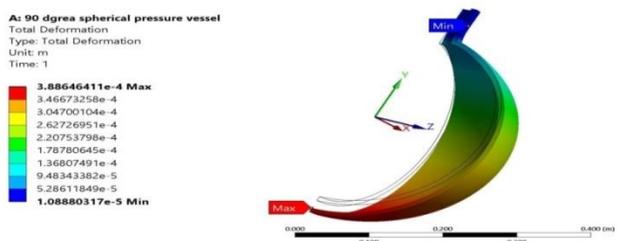


Figure 13: Total Deformation of Al7075-T6 with 500 Nanometers of Titanium

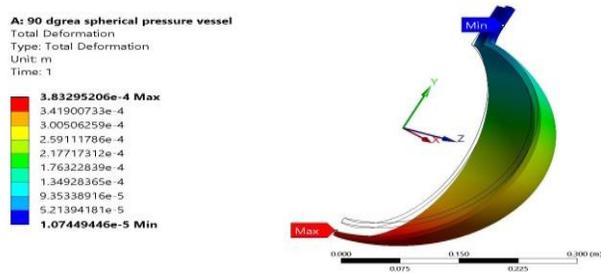


Figure 14: Total Deformation of Al7075-T6 with 500 Nanometers of Nickel.

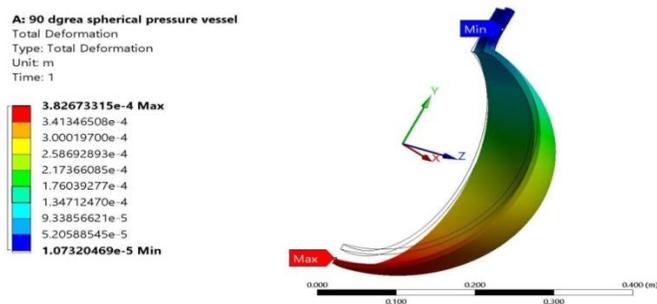


Figure 15: Total Deformation of Al7075-T6 with 900 Nanometers of Titanium.

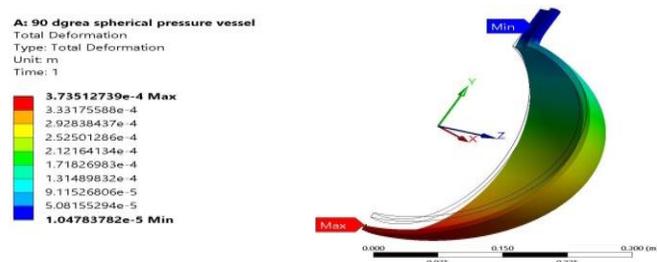


Figure 16: Total Deformation of Al7075-T6 with 900 Nanometers of Nickel.

Table-1: Improvement percentage in Maximum Total Deformation

	Titanium (Ti)		Nickel (Ni)	
	value	Improvement %	value	Improvement %
0.0 nm	3.96439864e-4	0.0	3.96439864e-4	0.0
100 nm	3.94850649e-4	0.4009	3.93722585e-4	0.6902
500	3.88646411e-4	1.9659	3.83295206e-4	3.4294

nm				
900	3.82673315e-4	3.4725	3.73512739e-4	6.1382
nm				

$$\text{The improvement percentage} = \left| \frac{\text{oldvalue} - \text{nwevlue}}{\text{oldvalue}} \right| * 100\% \dots (19)$$

Where, **Old value:** value before coating.

New value: value after coating.

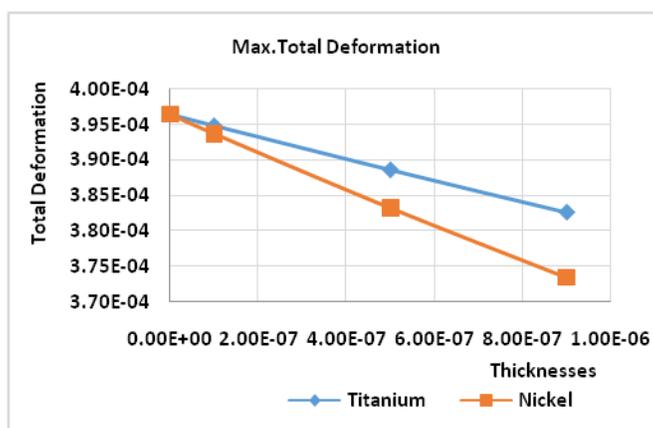


Figure 17: Comparison between Titanium and Nickel Nano Coating thickness improvement on maximum Total Deformation.

Figure (17) shows the value of improvement on thin-walled spherical vessel for increasing the resistance to Total Deformation after coating the surface of thin-walled spherical vessel which made of (Al 7075-T6) by different Nano thicknesses of Titanium and Nickel separately, starting coating from 100 Nanometers thickness of (Titanium and Nickel), the increasing the thicknesses of coating to (500 and 900 Nanometers) the lowest value of improvement in decreasing the Total Deformation is (0.4009%) for Titanium and the highest improvement in decreasing the Total Deformation is for Nickel about(6.1382%) between these two values the advantage of improvement it is for Nickel, it can make improvements (56.6%) more than Titanium.

b) Normal Elastic Strain: Elongation or contraction of a line segment due to stress it is the normal elastic strain was studied longitudinally and normally (hoop), as follows:

1) Normal Elastic Strain (longitudinal strain): By the same way which had been done with total deformation discussed above, table (2) shows the value of improvement in Normal Elastic Strain in the (X-axis) direction for a thin-walled spherical vessel, it is obvious that the maximum and minimum value of strain which is located in the vessel neck, increasing in one direction means decreasing in the other

direction, negative values mean that a contraction in this region is occurred.

Table 2: Improvement Percentage in Maximum Normal Elastic Strain (X-axis)

	Titanium (Ti)		Nickel (Ni)	
	value	Improvement %	value	Improvement %
0.0 nm	2.98887594e-3	0.0	2.98887594e-3	0.0
100 nm	2.97514615e-3	0.4615	2.96454998e-3	0.8206
500 nm	2.92165568e-3	2.3008	2.87164939e-3	4.0822
900 nm	2.87032658e-3	4.1302	2.78514992e-3	7.3147

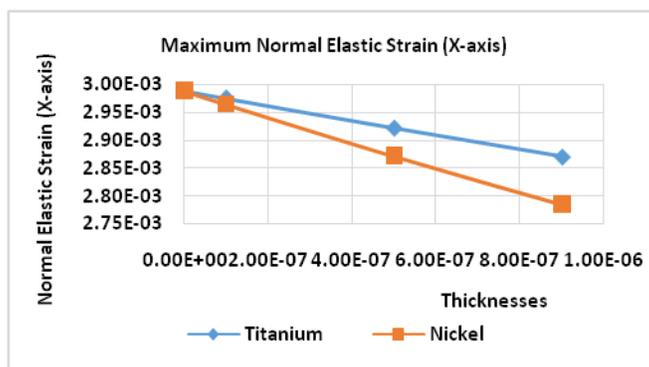


Figure 18: Comparison between Titanium and Nickel Nano Coating Thickness in Maximum Normal Elastic Strain (X-axis)

While, Figure (18) shows the value of improvement on thin-walled spherical vessel for increasing the resistance to Normal Elastic Strain (longitudinal strain) after coating the surface of thin-walled spherical vessel which made of Al 7075-T6 by different Nano thicknesses of Titanium and Nickel separately, started coating from 100 Nanometers of (Titanium and Nickel) thicknesses, then increasing the thicknesses of coating to (500 and 900 Nanometers). It can be seen that the lowest value of improvement in Normal Elastic Strain (longitudinal strain) is (0.4615%) for Titanium, and the highest improvement it is for Nickel (7.3147%), also the larger improvement can be seen in Nickel coating, which is about (56.4%) higher than Titanium.

2) Normal Elastic Strain (hoop strain): Table (3) shows the improvements in Normal Elastic Strain in the (Y-axis) direction for a thin-walled spherical vessel, it is evident that the maximum value of strain which is located at the middle of the vessel and the minimum value at the vessel neck.

Table 3: Improvement Percentage in Maximum Normal Elastic Strain (Y-axis)

	Titanium (Ti)		Nickel (Ni)	
	value	Improvement %	value	Improvement %
0.0nm	9.82097024e-4	0.0	9.82097024e-4	0.0
100nm	9.78520897e-4	0.3655	9.76008701e-4	0.6238
50nm	9.64471383e-4	1.8275	9.52388661e-4	3.1194
90nm	9.50816693e-4	3.2898	9.29879822e-4	5.6155

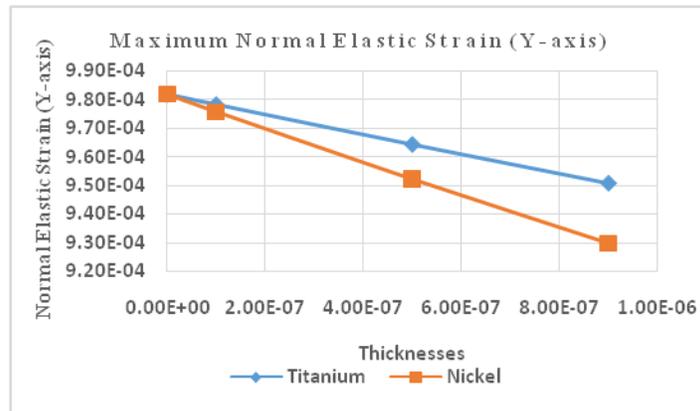


Figure 19: Comparison between Titanium and Nickel Nano Coating Thickness Improvement Maximum Normal Elastic Strain (Y-axis).

Figure (19) shows the value of improvement on thin-walled spherical vessel for increasing the resistance to Normal Elastic Strain (hoop strain) after coating the surface of thin-walled spherical vessel. It is clear that the lowest value of improvement in Normal Elastic Strain (hoop strain) is (0.3655%) for Titanium, and the highest improvement it is for Nickel (5.6155%), also again the larger improvement is found in Nickel coating, which is about (58.6%) higher than Titanium.

c) Normal Stress: Normal Stress is the stress which acts in a direction perpendicular to the area [Bansal, R.K., 2010.]. Also by the same procedure as above was analyzed longitudinally and normally l(hoop) as follows:

1) Normal Stress (longitudinal stress, X-axis): Longitudinal Normal Stress is the stress acting in a spherical vessel wall along the longitudinal axis, table (4) shows the improvement in longitudinal stress in a thin-walled spherical vessel.

Table 4: Improvement Percentage in Maximum Normal Stress (X-axis)

	Titanium (Ti)		Nickel (Ni)	
	value	Improvement %	value	Improvement %
0.0nm	2.06153552e6	0.0	2.06153552e6	0.0
100nm	2.05191643e6	0.4688	2.04519670e6	0.7989
500nm	2.01453305e6	2.3332	1.98284223e6	3.9687
900nm	1.97878315e6	4.1812	1.92481780e6	7.1029

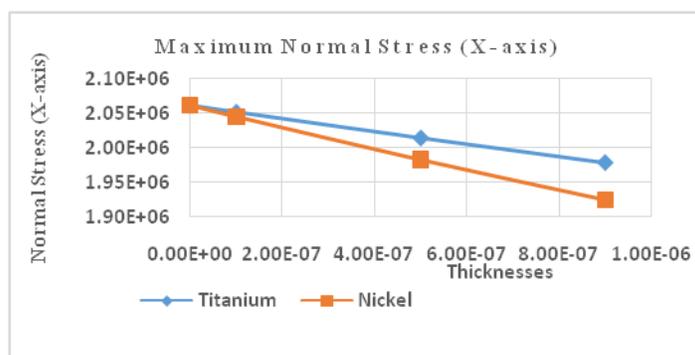


Figure 20: Comparison between Titanium and Nickel Nano Coating thickness Improvement Maximum Normal Stress (X-axis)

Figure-20 shows the value of improvement on thin-walled spherical vessel for increasing the resistance to Normal Stress (longitudinal stress) after coating the surface of thin-walled spherical vessel, it is clear that the lowest value of improvement in Normal Stress (longitudinal stress) is (0.4688%) for Titanium, and the highest improvement it is for Nickel (7.1029%), also the larger improvement is found in Nickel coating, which is about (58.86%) higher than Titanium.

2) Normal Stress (Hoop Stress, y-axis)

Hoop stress is the stress in a spherical vessel wall, acting circumstantially in a plane perpendicular to the longitudinal axis of the vessel, table (5) and figure-21 show the improvement in Normal Stress (hoop stress). Figure (21) indicates that the spherical vessel coated with Ni 900 Nanometers has the highest percentage of improvement in decreasing the Normal Stress (hoop stress), about 5.7471% compared to all other coatings. Also, it depicts that with the increase in the coating thickness there is an appreciable increase in the improvement. The larger improvement is found in Nickel coating, which is about (58.6%) higher than Titanium.

Table 5: Improvement Percentage in Maximum Normal Stress (Y-axis)

	Titanium (Ti)		Nickel (Ni)	
	value	Improvement %	value	Improvement %
0.0nm	1.00175610e6	0.0	1.00175610e6	0.0
100 nm	9.98024075e5	0.3739	9.95402406e5	0.6383
500nm	9.83366919e5	1.87	9.70767044e5	3.1922
900nm	9.69131450e5	3.3664	9.47312896e5	5.7471

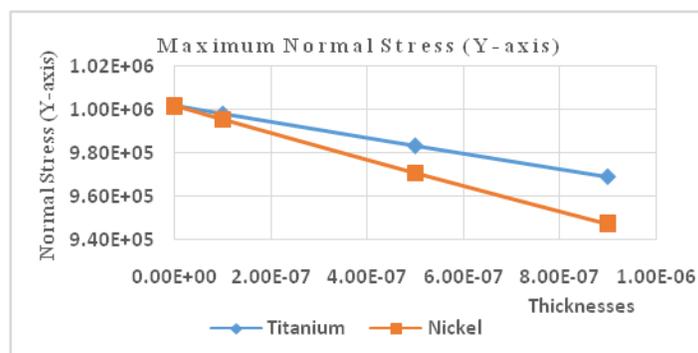


Figure 21: Comparison between Titanium and Nickel Nano Coating Thickness in Maximum Normal Stress (Y-axis).

d) Equivalent Stress: Equivalent Stress (also called Von Misses stress) is often used in design work because it allows any arbitrary three-dimensional stress state to be represented as a single positive stress value. Equivalent Stress is part of the maximum Equivalent Stress failure theory used to predict yielding in a ductile material. The test results for Equivalent Stress are tabulated in the table (6) and figure (22) indicate that the spherical vessel coated with Ni 900 Nanometers has the highest percentage of improvement in decreasing the Equivalent Stress (7.3358%) compared to all other coatings. Also, they depict that with the increase in the coating thickness there is an appreciable increase the improvement. Again the larger improvement is found in Nickel coating, which is about (55.3%) higher than Titanium.

Table 6: Decreasing Percentage in Maximum Equivalent Stress

	Titanium (Ti)		Nickel (Ni)	
	value	Improvement %	value	Improvement %
0.0nm	2.20215702e6	0.0	2.20215702e6	0.0
100	2.19220712e6	0.4539	2.18416913e6	0.8236

nm				
500 nm	2.15339847e6	2.2643	2.11550008e6	4.0963
900 nm	2.11610677e6	4.0664	2.05165105e6	7.3358

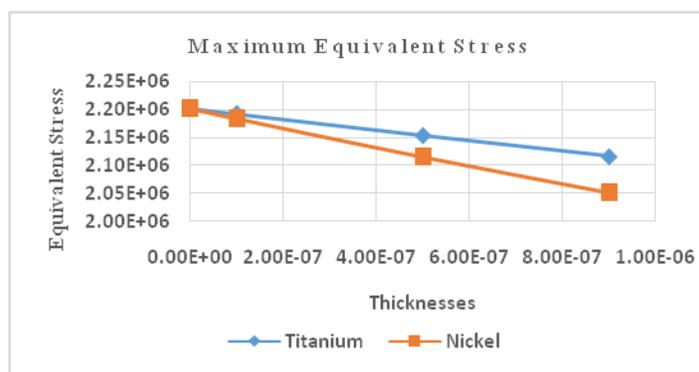


Figure 22: Comparison between Titanium and Nickel Nano Coating Thickness in Maximum Equivalent Stress.

c) **Shear Stress:** Shear stress is the stress induced in a body when subjected to two equal and opposite forces which are acting tangentially across the resisting section (Bansal, R.K., 2010).

1) Shear Stress in XY plane

Table (7) shows the improvement in Shear Stress in XY plane

Table 7: Decreasing Percentage in Maximum Shear Stress in XY plane

	Titanium (Ti)		Nickel (Ni)	
	value	Improvement %	value	Improvement %
0.0nm	5.50635833e5	0.0	5.50635833e5	0.0
100nm	5.48691844e5	0.3543	5.47325146e5	0.6049
500nm	5.41048542e5	1.7720	5.34468677e5	3.0249
900nm	5.33608417e5	3.1910	5.22194865e5	5.4464

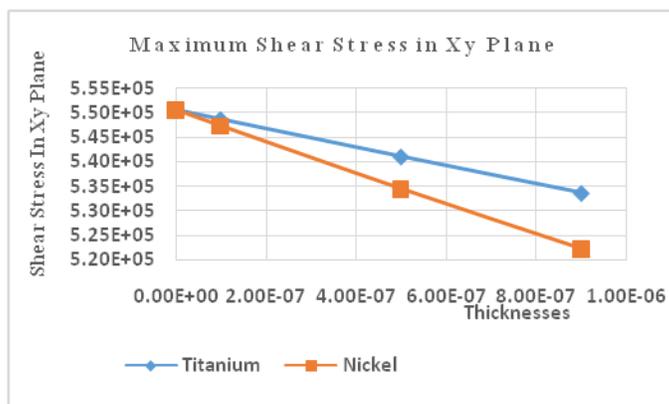


Figure 23: Comparison between Titanium and Nickel Nano Coating Thickness in Maximum Shear Stress in the XY plane

The test results for Shear Stress in the XY plane are also shown in figure (23), which illustrates that the spherical vessel coated with Ni 900 Nanometers has the highest percentage of improvement in decreasing the Shear Stress in XY plane (5.4464%) compared to all the other coatings. Also, it depicts that with the increase in the coating thickness there is an appreciable increase in the improvement. Again the Nickel has improvements (58.6%) higher than Titanium.

2)Shear Stress in XZ plane: Table (8) and figure-24 show the improvement in Shear Stress in the XZ plane. The results show that the spherical vessel coated with Ni 900 Nanometers has the highest percentage of improvement in decreasing the Shear Stress in XZ plane (20.7240%) compared to all the other coatings, and the Nickel has improvements (56.1%) more than Titanium.

Table (9) shows a summary for all types of stresses which have been analysed and the improvement percentage on these stresses after coating with Nano thicknesses of Titanium and Nickel.

Table 8: Decreasing Percentage in Maximum Shear Stress in XZ plane

	Titanium (Ti)		Nickel (Ni)	
	value	Improvement %	value	Improvement %
0.0nm	9.55220253e3	0.0	9.55220253e3	0.0
100nm	9.43021767e3	1.2936	9.33437257e3	2.3336
500nm	8.97289643e3	6.4562	8.56243172e3	11.5595
900nm	8.55764045e3	11.6219	7.91243169e3	20.7240

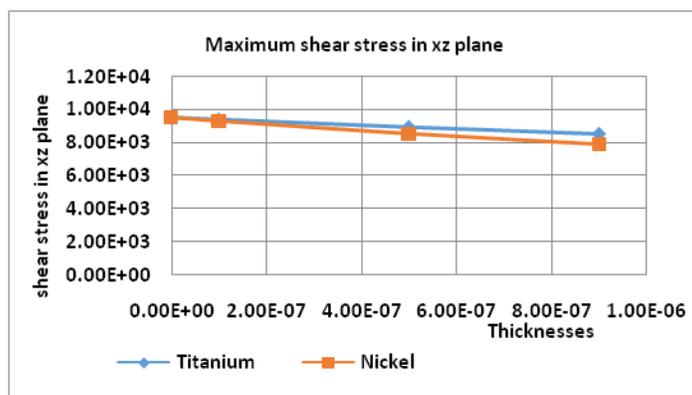


Figure 24: Comparison between Titanium and Nickel Nano Coating Thickness in Maximum Shear Stress in the XZ plane.

Table 9: Summary of Improvement Percentage

	Improvement of Titanium (Ti) %			Improvement of Nickel(Ni) %		
	100 nm	500 nm	900 nm	100 nm	500 nm	900 nm
Total Deformation	0.4009	1.9659	3.4725	0.6902	3.4294	6.1382
Normal Elastic Strain X axis	0.4615	2.3008	4.1302	0.8206	4.0822	7.3147
Normal Elastic Strain Y axis	0.3655	1.8275	3.2898	0.6238	3.1194	5.6155
Normal Stress X axis	0.4688	2.3332	4.1812	0.7989	3.9687	7.1029
Normal Stress Y axis	0.3739	1.87	3.3664	0.6383	3.1922	5.7471
Equivalent Stress	0.4539	2.2643	4.0664	0.8236	4.0963	7.3358
Shear Stress XY plane	0.3543	1.7720	3.1910	0.6049	3.0249	5.4464

Shear Stress XZ plane	1.2936	6.4562	11.6219	2.3336	11.5595	20.7240
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Conclusions

From the results of this work, the following conclusions can be drawn.

- The aluminum 7075-T6 thin walled spherical vessel was successfully coated theoretically by modeling with Titanium and Nickel by using ANSYS software with different Nano thicknesses of 100nm, 500nm, and 900nm respectively.
- The 900nm Nickel coated aluminum 7075-T6 thin walled spherical vessel showed a better improvement in their mechanical properties, where: The percentage of improvement in increasing the resistance in Total Deformation (6.1382%), the Normal Elastic Strain X-axis (7.3147%), the Normal Elastic Strain Y-axis (5.6155%), the Normal Stress-axis(7.1029%), the Normal Stress-axis(5.7471%), the Equivalent Stress(7.3358%), the Shear Stress XY- plane(5.4464%) and the Shear Stress XZ- plane(20.724%).
- The improvement percentage of the coated thin-walled spherical vessel by 500nm Nickel it is approximately equal to the improvement percentage of the coated thin-walled spherical vessel by 900nm Titanium.
- Nickel and Titanium can helping in protecting against corrosion and improve wear resistance, as well as increasing the thickness of a surface.
- Nickel and Titanium can enhance the appearance of the spherical vessel by adding brightness.
- The Spherical vessel with Nickel coated exhibited the highest percentage of improvement in comparison with Titanium under the conditions.

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