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Investigation on Joint dynamic property of Nanoclay based Redundant SCARA robot

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Abstract. *In recent years, for robot structural design, the conventional materials are replaced by alternative nanocomposite materials for its enhanced properties. This paper describes the impact of Nanoclay reinforced AA 5083 as a novel material replacement for the design of redundant SCARA (RSCARA) robot by varying the composition of Nanoclay in weight percentage (0, 1 and 2 wt%). The RSCARA parts are modelled by three dimensional (3D) computer aided design (CAD) modeling Solid Works package by imparting the material properties of newly developed nanocomposites. The model developed was exported to MATLAB/ Simscape Multibody Simulation environment and converted into multibody electromechanical system blocks. The required Input/output primitives are consigned for the joint blocks and the dynamic parameter torque was derived by the Simscape Multibody simulation. The results of the simulation regarding the dynamic performance obtained for RSCARA solid and round hole perforated manipulator main arm and fore arm links assigned with Nanoclay reinforced AA 5083 material is expressed in this research work.*

Keywords: *Redundant SCARA Robot; AA 5083; Nanoclay; Dynamic performance; SolidWorks, Simscape Multibody*

Introduction

In designing a robot the Material is very important, because it improves the strength, stiffness, damping co-efficient, wear, corrosion resistance with economical production costs. Aluminium alloys, magnesium alloys, titanium alloys, polymer matrix and metal matrix composites have all been employed in robotics in recent years. The robot makers preferred aluminium alloys because of high strength-to-weight ratio, low weight, low cost, and extended endurance. A researcher previously created the movable parts of an articulated robot out of

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Aluminum alloy 6061-T6 for superior corrosion resistance, workability and low cost. [1, 2]. Due to concerns with rigidity, composite structures are being used in novel ways on robot components. To accomplish rapid mobility and positioning precision, robot material with a high density and specific stiffness can be employed. If the material damping is high, the robot's structural vibration may be dissipated. Steel and aluminium aren't strong enough to achieve it. These materials have specific damping and stiffness not sufficient for robot construction, but Composites are superior in damping and stiffness [3].

Reinforcement materials are used at the Nanosize level to increase the strength to weight ratio and its attributes even further. The Nano size material has little impact on weight, but it does increase the material's qualities in relation to the manufacturing technology used to make the Nano composites [4]. Nanoclay has been introduced as one of the major reinforcement material for aluminium metal matrix nanocomposites. In the recent years, various researchers involved in analyzing the nature and impact of Nanoclay. The material synthesis, characterization, stability, morphological properties and polymer nanocomposites reinforced with Nanoclay manufacturing was also carried out by the researchers along with developing new material with Nanoclay as originators [5-8].

The several investigators conducted various performance and control technique studies in SCARA robot. Steel is utilised for non-moveable parts while aluminium is used for movable parts [9]. SCARA is an economical robotic manipulator with four degrees of freedom (DOF) limited working volume by means of Revolute (R), Revolute (R), and Prismatic (P) configuration [10]. It is applicable for light duty purposes like electronics component stacking, inspecting products, wafer masks conveying, touch panel evaluation component insertion, deburring, chamfering, tapping, screw tightening, packing, drilling, gluing parts loading and unloading in automated production line [11]. The redundant SCARA robot (RSCARA) is proposed in this study to examine the influence of composite material properties is shown in

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Figure 1. Compared to non-redundant manipulators, redundant are agile in performing a variety of jobs[12]. Several studies have been carried out to assess the dexterity of robots using numerical simulation. The wide literature review reveals that robot modelling and simulation are critical for developing a robotic system in less time and at a lower cost [13].

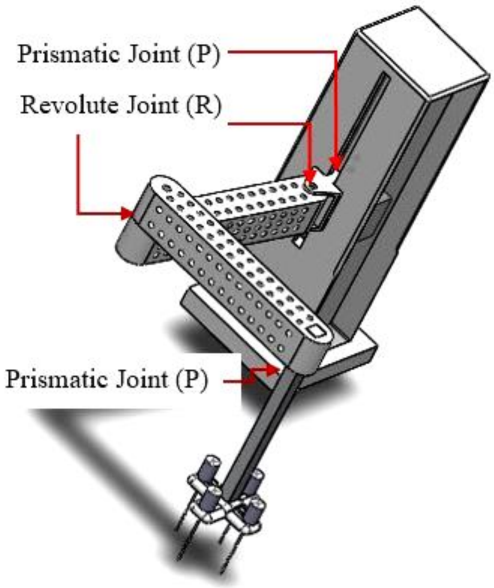

Figure 1. SolidWorks model of RSCARA robot

In this work the authors intended to assess the performance of newly developed Nanoclay reinforced Aluminium Metal Matrix Composites (AMMCs) material in PRRP configuration RSCARA with MTEE utilizing SolidWorks and MATLAB/Simscape Multibody tools. This is a new attempt, which is not testified hitherto by other researchers. Industrial and measuring robots with the designed composite arm is incorporated according to the existing operational conditions. Orthotropic composite materials were used to develop a model of single link manipulator arms simultaneously computer simulation was done to observe the outcomes. It was identified that the vibration during motion is very less consequently improved energy savings in robotic arms which is made of composite material than that of steel, aluminium, boron/epoxy, and graphite/epoxy. The conventional Aluminium material was replaced with graphite reinforced polymer matrix composite as a material for direct-drive SCARA robot arm used for printed circuit board assembly operation. The researchers observed that the static and dynamic parameters such as, natural frequency, damping and weight reduction has noticeably improved [14].

The MATLAB/Simulink simulation was earlier used to observe and verify the joint motion parameters of non redundant SCARA robot single tool end effector (STEE) [15-20]. Instead of graphical programming environment in MATLAB/Simulink the researchers prefer MATLAB/Simscape Multibody, the physical model simulation environment incorporated with solid modelling software for analyzing the dynamic parameters such as position, velocity and acceleration and actuator torque of SCARA with STEE [21, 22].

Since 80s the researchers involved in the research on redundant robots using different simulation techniques are superficies its performance through structural changes and by employing suitable controllers. The computer aided simulations are used to determine the task performing priority of redundant robots and its effectiveness [23]. The improved dynamic performance of the redundant mechanism designs was also investigated using simulation techniques [24, 25].

The 3D CAD simulation is facilitating the researchers in the development of redundant SCARA robots. The 3D CAD/CAM simulation was applied to study the redundant SCARA robot end effector trajectory to avoid obstacles by developing the computational algorithm for manipulator movements. The space and joint coordinates of redundant SCARA was predicted by adopting MATLAB simulation [26]. The researchers developed the dynamic model of 5DOF SCARA using MATLAB/Simulink and conducted simulation to analyze the actuator dynamics embedded with different controllers for tracking the manipulator path [27].

The authors of this article used MATLAB/Simscape Multibody connected to 3D modelling software SolidWorks to conduct a simulation study to examine the dynamic behaviour of redundant SCARA with MTEE [28]. When compared to the traditional approach of new robot development, the findings of the research work showed that designing and developing a SCARA with the requisite end effector may be done in less time and expense. Thus, various research works conducted by eminent investigators exposed that the simulation tool are a very essential economical tool to develop the SCARA robot to meet with competence of the industrial world.

The impact of Nanoclay reinforced alloy AA 5083 on redundant SCARA robot design was investigated in four phases in this study. Firstly, a liquid state stir casting procedure is used to strengthen an aluminium alloy (AA 5083) with different Nanoclay weight percentages. The mechanical characteristics of the newly created nanocomposite materials were also observed experimentally in the second phase. Thirdly, using SolidWorks, the choosen material primitives are incorporated to the computer-aided model of RSCARA. The robot's multi body system block diagram (MBSBD) was constructed in the fourth phase by exporting 3D CAD solid model diagrams to the Simscape Multibody simulation environment, and the manipulator joint torque was measured.

Material Design

Aluminium Metal Matrix Composites (AMMCs) are prepared by changing the proportion of montmorillonite (Nanoclay) particles. Nanoclay procured consists of 1 nm thick layer of aluminosilicate stacked into multilayer of 10 µm. AA 5083 was mixed with various weight percentage (0, 1, 2) of Nanoclay by liquid state stir casting method. Then at 750ºc, AA 5083 billets was mixed with graphite crucible to change into liquid form by allowing the phase transformation for 210mins. The preheating of Nanoclay for 500ºC was carried out prior to mixing the reinforcement with matrix material. To control the oxidation, the liquid matrix material was degassed for 4 mins. The preheated Nanoclay material was mixed with matrix material by stirring at 250rpm for 2 mins [29-31]. The molten Nanoclay metal was dispensed in a 110x100x10mm3 mould to get a Nanoclay composite material with homogeneous dispersion pattern and it was allowed to get solidified for 15mins. Similarly, the same procedure was adopted for the remaining compositions.

Table 1. Mechanical properties of AA 5083 and Nanoclay

Material used	Density (g/cm3)	Youngs modulus (Gpa)	Tensile Strength(Mpa)	Poisson's ratio	Shear modulus (Gpa)
AA 5083	2.702	72.32	175.35	0.339	26.54
AA 5083-1 wt% Nanoclay	2.724	71.45	174.55	0.337	26.38
AA 5083-2 wt% Nanoclay	2.732	71.04	173.30	0.336	26.25

To understand the microstructure characterization of AA 5083, Nanoclay and Nanoclay reinforced AA 5083 composites Scanning Electron Microscope (SEM) and Field-Emission Scanning Electron Microscope (FE-SEM) linked to energy dispersive X-ray analysis (EDAX) were used. The Foremost elements in Nanoclay are O, Al, Si, Mg, Fe as EDAX image depicted in Figure 2 (a). The EDAX image presented in the Fig. 2 (b) represents the presence of Al and Mg with high peak values for the as cast matrix material. In Figure 3 (a) & (b), FE-SEM visuals of Nanoclay indicates the multilayered Si-O-Al structure. The mechanical property of the composites was enhanced by means of Nanoclay dispersion pattern in matrix material.

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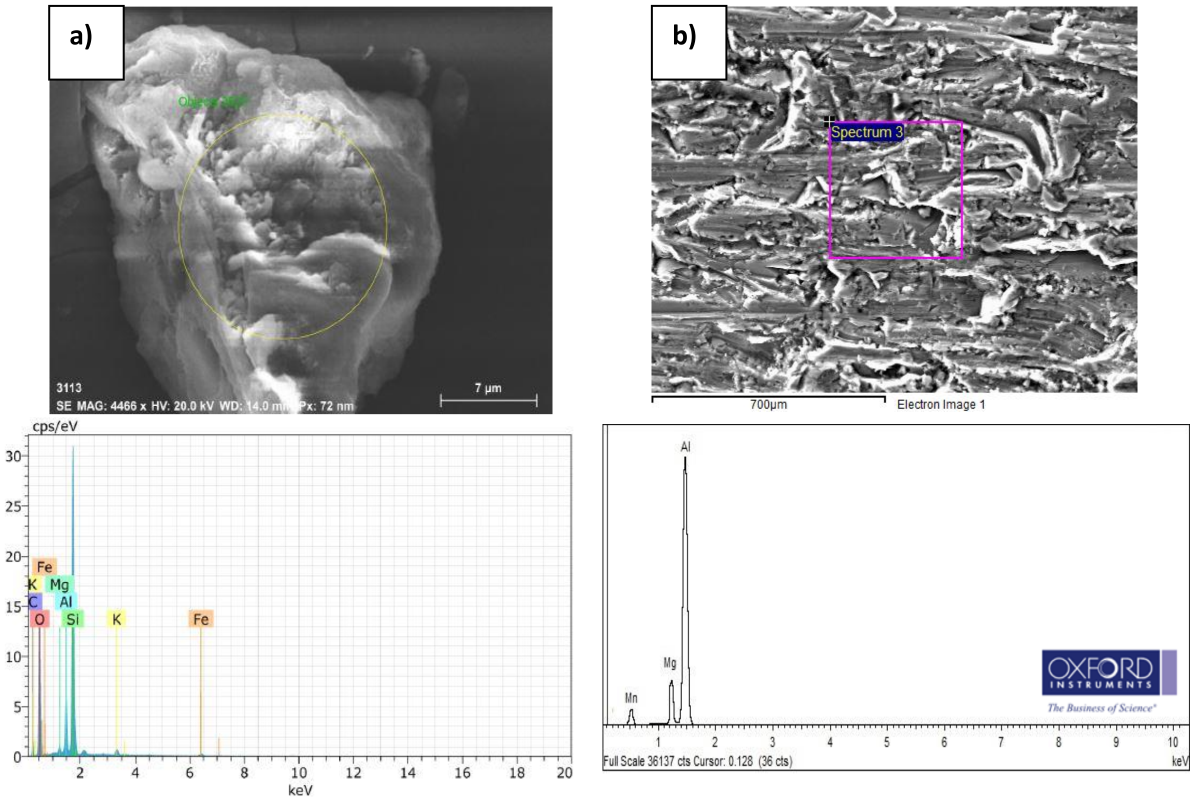

Figure 2. EDAX image of (a) nanoclay; (b) AA 5083 alloy

The phase change characteristics in the newly developed composites by adding Nanoclay with matrix material was also studied by X-ray diffraction analysis (XRD). Figure 4 (a) illustrates the phase changes of Al and Mg2Al3 in AA 5083 material after adding 1wt% and 2wt%, Nanoclay of with AA 5083. Figure 4 (b) & (c) image indicates the existence of Si and Al_2O_3 because of interfacial reinforcement and matrix material bonding.

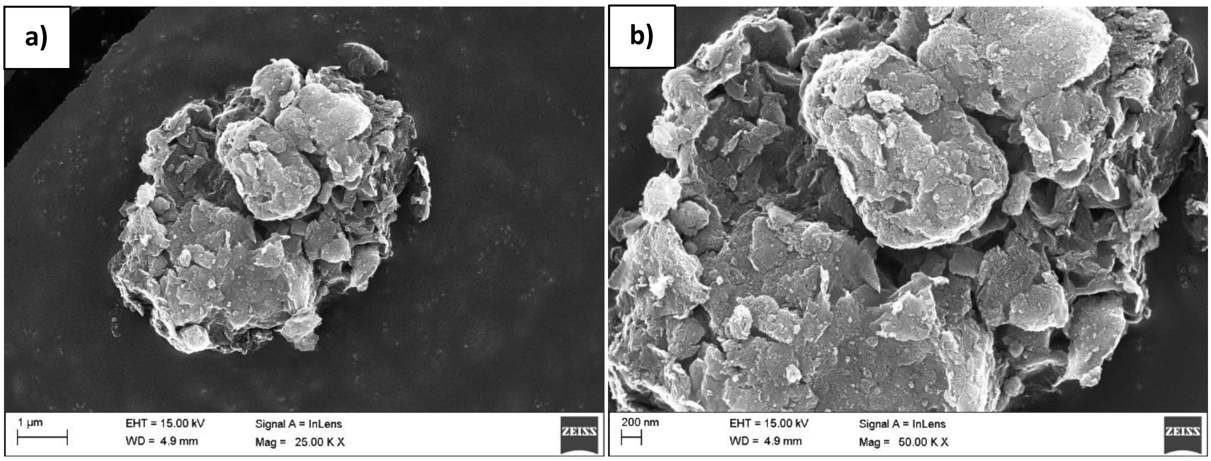

Figure 3. FE-SEM image of

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(a) Nanoclay MMT K10 Layer (b) Nanoclay MMT K10 Magnification

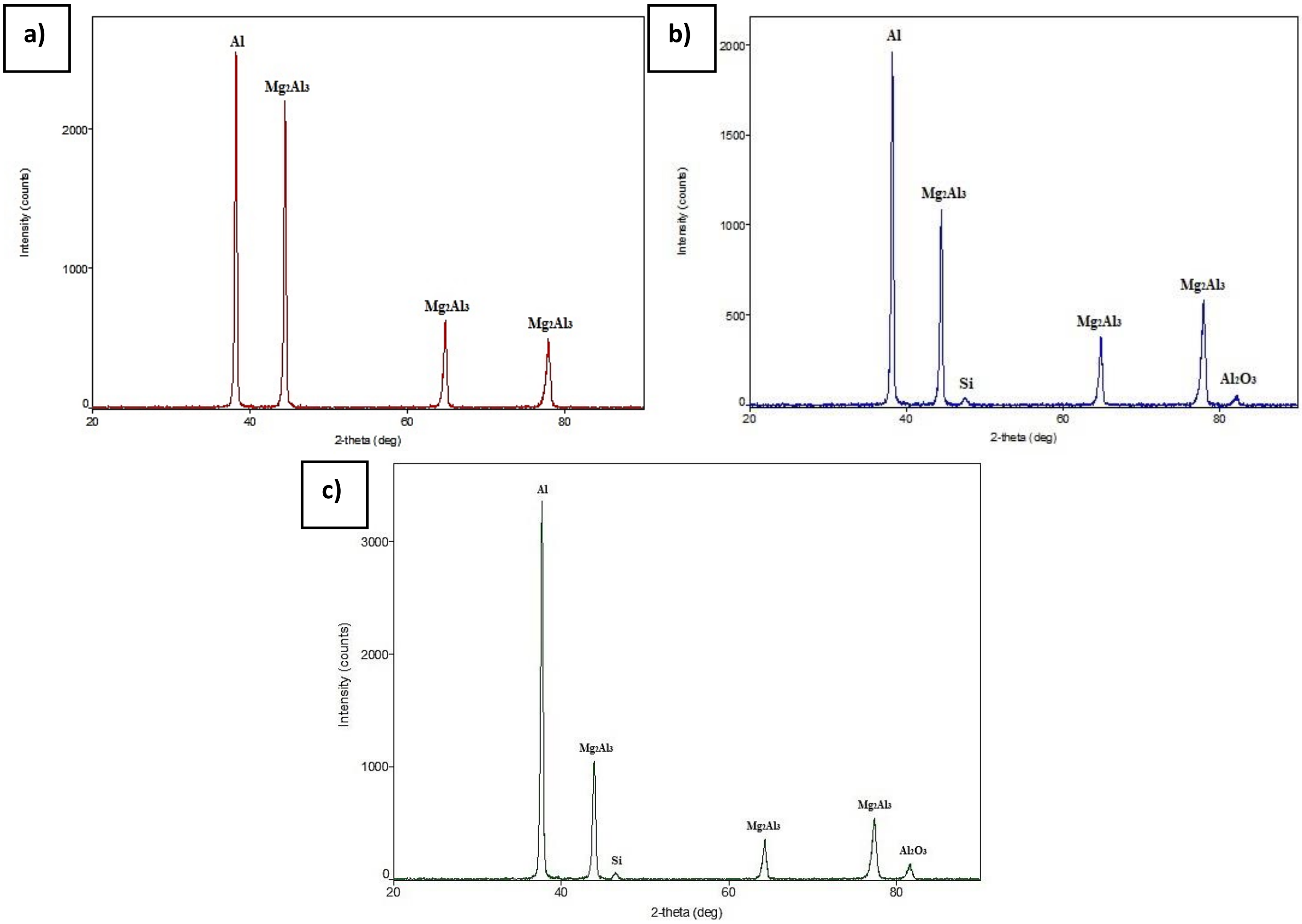

Figure 4. X-RD image of (a) AA 5083 alloy- 0 wt% of Nanoclay;

(b) AA 5083 alloy -1 wt% of Nanoclay; (c) AA 5083 alloy 2 wt% of Nanoclay

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Modelling of RSCARA

The RSCARA with MTEE is created utilizing the capability of 3D CAD modelling SolidWorks software as shown in the Figure 5 [28]. In Figure 5, the Denavit – Hartenberg notations of the redundant SCARA are well defined, which will support the kinematic modelling. The material assigned to main arm, forearm and prismatic arm is AA 5083-Nanoclay whereas alloy steel for other parts of the proposed SCARA.

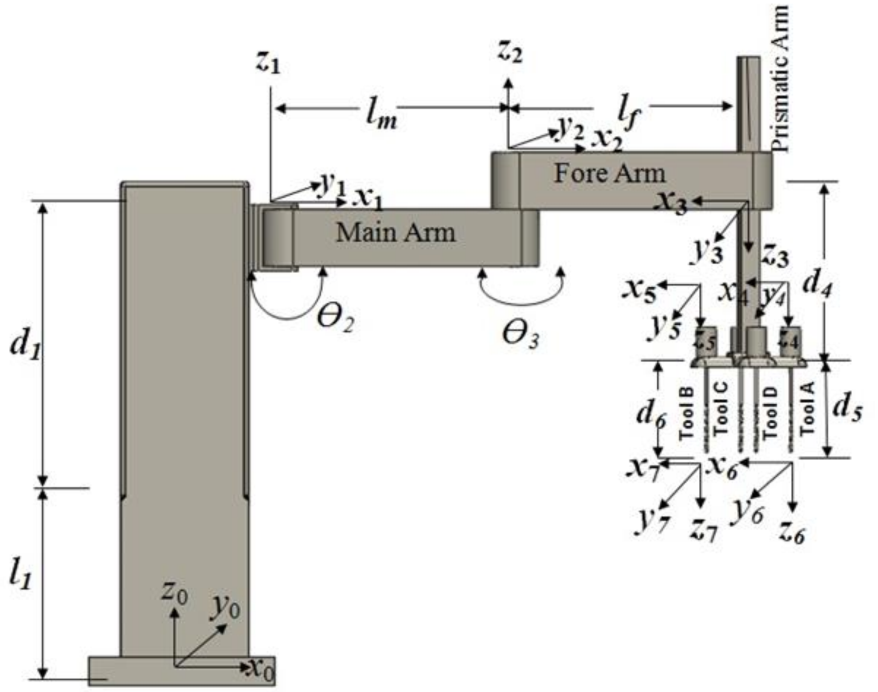

Figure 5. Front view and D-H parameters of RSCARA with Multiple tool

In figure 5, *lm* = main arm length in mm, *lf* = forearm length in mm, *la* = Tool A arm length with respect to the prismatic arm axis (Z_3), l_b = Tool B arm length for with respect to the prismatic arm axis (Z_3) (It is assumed as - l_b because of its negative direction). J_1, J_2 = revolute joint 1, 2. d_1, *to* d_6 = offset length in-between the successive links. The 3D CAD model is based on the following dimensions and D-H parameters. $lp = 100mm$, $d_1 = 300mm$, $l_m = 300mm$, $l_f = 300mm$, $d_2 = 0$, $l_a = 100mm$, $d_3 = 0$, $d_4 = 5mm\text{-}300mm$, $l_b = 100mm$, $d_5 = 80mm$, $d_6 = 80mm$.

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Kinematic model based on forward and inverse kinematics [32-35]. The equations (1-4) [28] represents the end effector tool positions A, B, C and D respectively.

$$x_A, y_A, z_A = ((l_a + l_f)C_{23} + l_m C_2, (l_a + l_f)S_{23}, d_1 + l_p - d_5 - d_4) \quad (1)$$

$$x_B, y_B, z_B = ((l_f - l_b)C_{23} + l_m C_2, (l_f - l_b)S_{23} + l_m S_2, d_1 + l_p - d_6 - d_4) \quad (2)$$

$$x_C, y_C, z_C = (l_f C_{23} + l_m C_2, l_f S_{23} + l_m S_2, l_p + d_1 - d_4 - d_M) \quad (3)$$

$$x_D, y_D, z_D = (l_f C_{23} + l_m C_2, l_f S_{23} + l_m S_2, l_p + d_1 - d_4 - d_M) \quad (4)$$

Whereas S_2 and C_2 represents sine and cosine trigonometric joint angles function. S_{23}, C_{23} indicates *Sin* $(\Theta_2 + \Theta_3)$ and *Cos* $(\Theta_2 + \Theta_3)$. In Fig. 1, Θ_2 and Θ_3 is the angle displaced by the revolute joint 1 and 2 respectively [28].

Simscape Multibody Simulation

Simscape Multibody uses the CAD solid model to construct and solve the multibody system's equations of motion [36]. As shown in figure 6, it is depicted as a series of blocks denoting bodies, restrictions, joints, and force components. Simscape Multibody allows you to change the structure while maintaining optimum system restrictions, and the simulation results may be examined in a fraction of the time [37].

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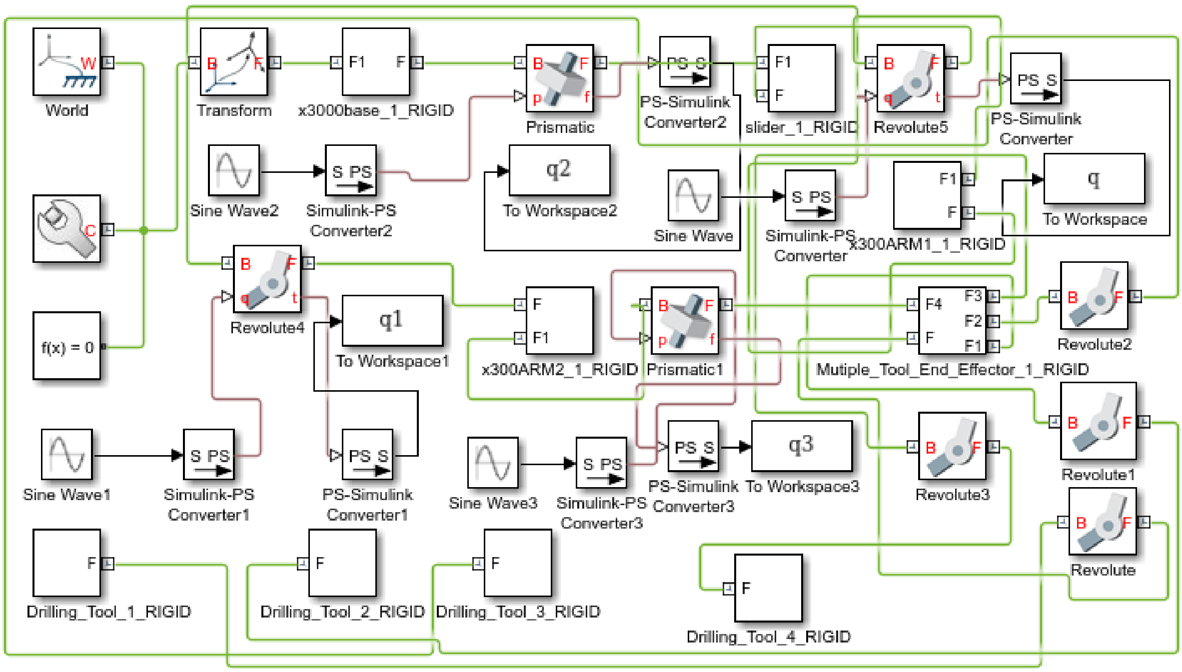

Figure 6. MBSBD of RSCARA to find the torque at revolute joints

The proposed RSCARA's CAD model was transferred to Simscape Multibody environment in this study using the Simscape Multibody connection activated in SolidWorks modelling site. The export procedure produces an XML file, which is opened in the Simscape Multibody second generation environment. The multibody system block diagram is created using this method, with interconnected blocks representing stiff body linkages and joints. The input parameters are given to the robotic system's blocks representing the joints in order to calculate the output of actuator dynamic performance. Importantly, workspace blocks are used to assign actuation primitives to obtain torque output. The highest torque was measured for the angle displaced by the main arm and fore arm by 90^0 for a time period of 10 seconds, according to the graph. As illustrated in figure 7, the three-dimensional graphical display in the Simscape Multibody Explorer window revealed the robotic system dynamics. Using the Simscape Multibody second generation simulation approach, the torque and dynamic parameters acting in the joints of the RSCARA were studied in this part.

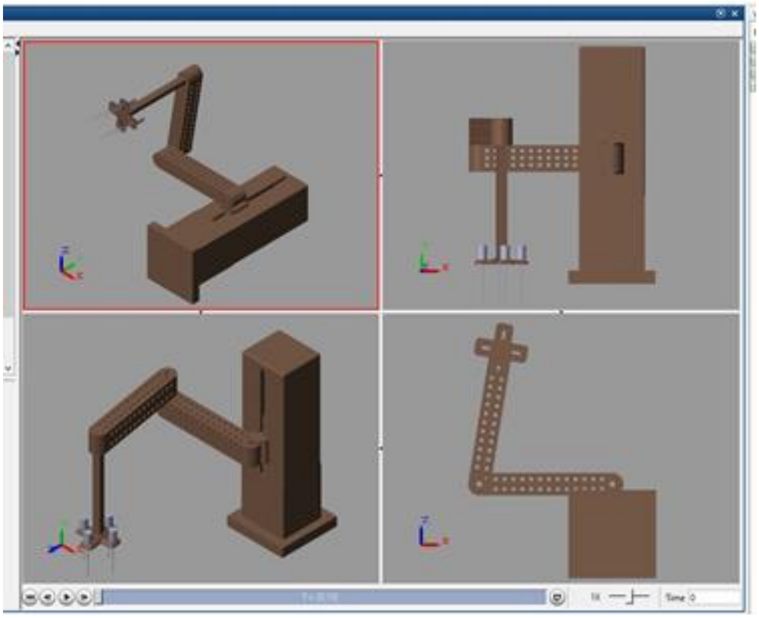

Figure. 7. Simscape Multibody explorer view of the RSCARA robot simulation

Simulation Results and discussion

The Nanoclay reinforced AA 5083 material with 0 wt% Nanoclay, 1 wt% Nanoclay, and 2 wt% Nanoclay. For main arm, forearm, prismatic arm of the RSCARA CAD model, Nanoclay was assigned as a bespoke material according to Table 1. The simulation was performed using Simscape and torque values are observed. Table 2 shows the observed torque values in with the material allocated to the robot links.

Table 2. Customized Material Vs Dynamic parameter

Material used	Torque (Nm)			
	Solid Material link		Perforated Material link	
	Joint 1	Joint 2	Joint 1	Joint 2
AA 5083-0wt%	61.86	31.12	58.11	27.43
AA 5083-1wt%	62.36	31.38	58.58	27.65
AA 5083-2wt%	62.54	31.47	58.75	27.73

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The joint actuator input receives the needed Sine wave and Simulink-PS (SPS) convertor. In the Simscape Multibody schematic, the PS - Simulink (PSS) blocks are added to joint actuator output. The joint torque sensing primitives of the revolute joints represented in the Simscape Multibody blocks and torque values observed in Fig. (8-13) for time instant t=10s through the workspace. Table 2 shows the torque measured in the revolute joints of solid and perforated designed main and forearm of the proposed robot for modified Nanoclay reinforced materials of 0% Nanoclay, 1% Nanoclay, and 2% Nanoclay.

In the figure 8, joint 1 torque value is observed as 58.11Nm and joint 2 as 27.43Nm, if AA 5083 – 0% Nanoclay is RSCARA fore arm and main arm links design material in solid form.

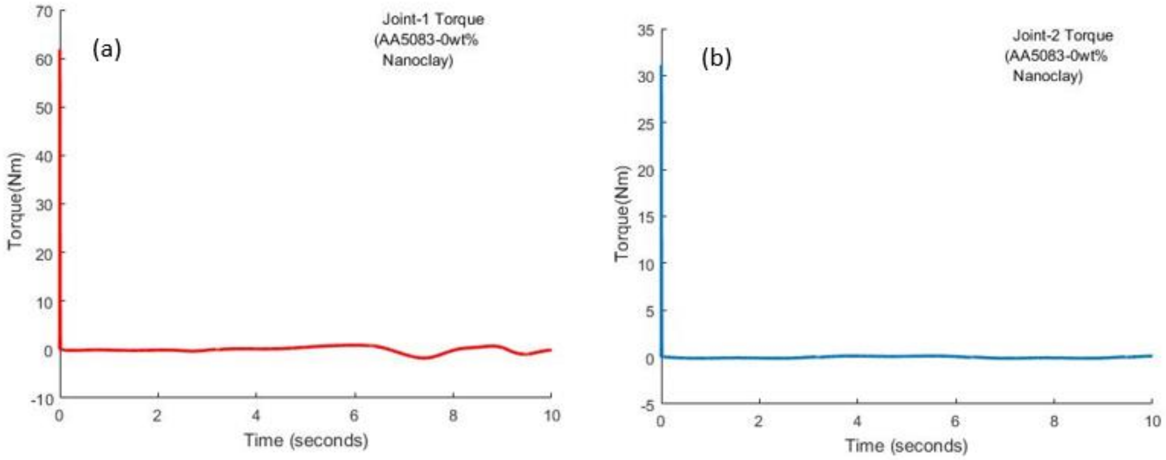

Figure 8. Joint torque J1 and J2 if material is AA 5083 – 0 % Nanoclay

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Joint 1 and 2 torque value was observed as 58.11Nm and joint 2 as 27.43Nm, if AA 5083 – 0% Nanoclay is fore arm and main arm links design material with round hole perforation is shown in figure 9.

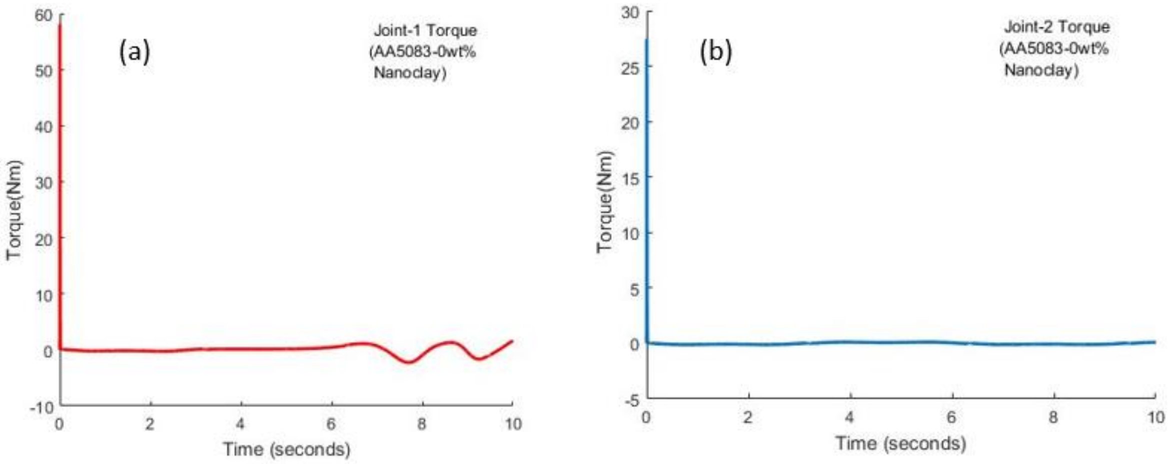

Figure 9. Joint torque J1 and J2, if material is AA 5083 – 0 % Nanoclay with round hole perforated link

The joint torque 1 is 62. 36 Nm and Joint 2 is 31.38Nm as depicted in figure 10, if the material used is AA 5083 – 1% Nanoclay in the main arm and fore arm links of solid material design.

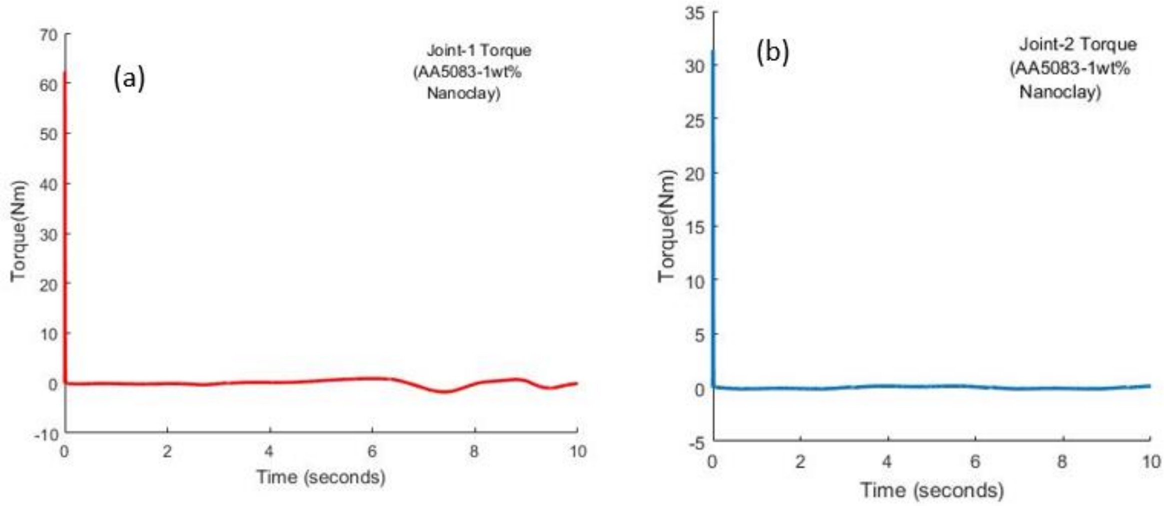

Figure 10. joint torque J1 and J2, if material is AA 5083 – 1% Nanoclay

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If the material assigned for the forearm and main arm with perforated material is AA 5083 –1% Nanoclay, the torque in the joints 1 and 2 is observed as 58.58Nm and 27.65Nm are presented in the figure 11.

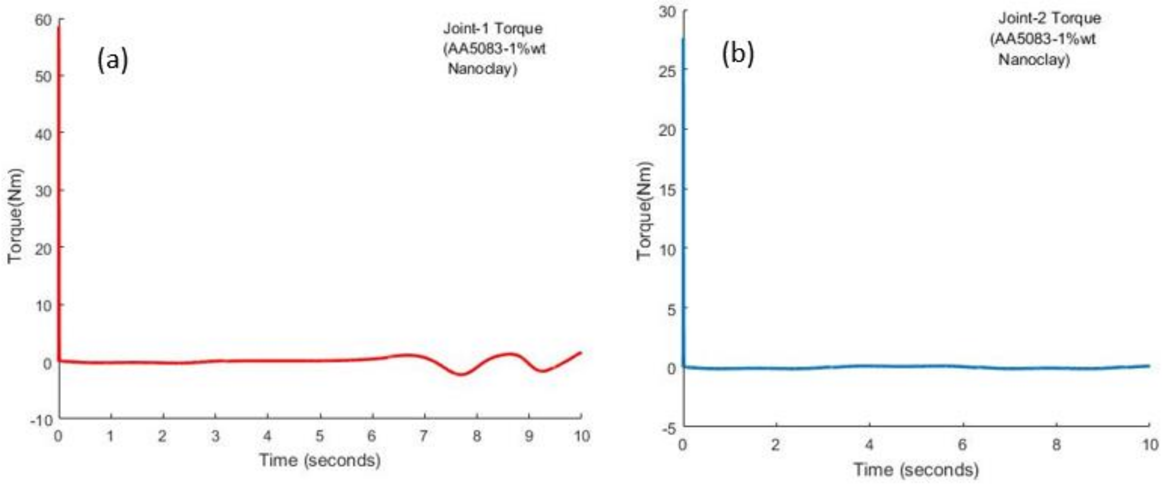

Figure 11. Joint torque J1 and J2 if material is AA 5083 – 1% Nanoclay with round hole perforated link.

If the material assigned for the forearm and main arm with solid material design is AA 5083 –2% Nanoclay, the torque in the joints 1 and 2 is observed as 62.54Nm and 31.47 Nm are illustrated in the figure 12.

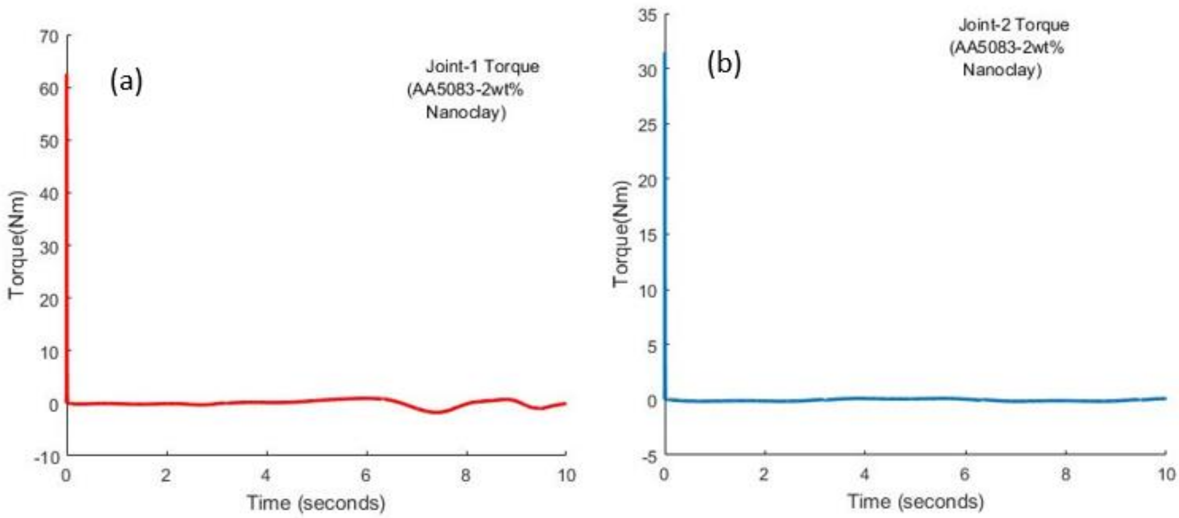

Figure 12. Joint torque J1and J2, if material is AA 5083 – 2% Nanoclay

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If the material assigned for the forearm and main arm with perforated material design is AA 5083 –2% Nanoclay, the torque in the joints 1 and 2 is observed as 58.75Nm and 27.73Nm are shown in figure 13.

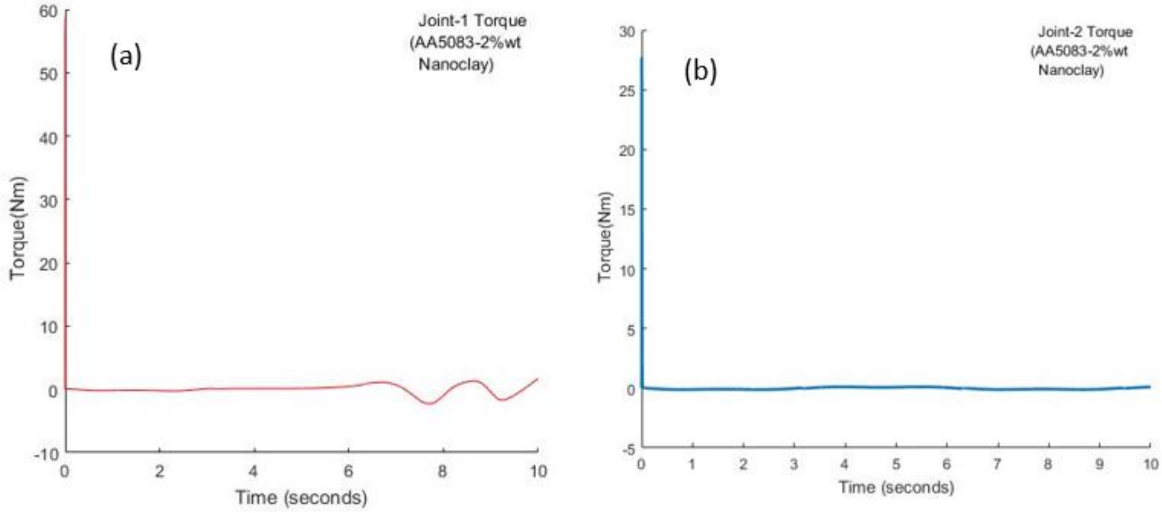

Figure 13. Joint torque J1 and J2 if material is AA 5083 – 2% Nanoclay with round hole perforated link.

In this research work, AA 5083 reinforced with 0 % Nanoclay, 1 % Nanoclay and 2 % Nanoclay is used as design material for the robot manipulator solid and round hole perforated links because it has good mechanical properties with improved damping property. For AA 5083 with 0 % Nanoclay, the torque value observed was 61.86Nm, 31.12Nm and 58.11, 27.43Nm in the main arm and fore arm in the solid link and perforated link joints. The addition of 1 % Nanoclay in AA 5083 shows 0.8%, 0.83% and 0.8%, 0.8% of change in torque values if solid and perforated matrix material is assigned for main arm and fore arm links. Similarly, the 2 % of Nanoclay accumulation in AA 5083 shows 1.09%, 1.12% and 1.10%, 1.09% of change in the torque values.

The 2 weight fraction Nanoclay shows better mechanical, damping property. The variation in torque levels is quite small, and it is thought to be within safe limits. The material

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for producing the primary and forearm of the redundant SCARA robotic manipulator should be AA 5083 – 2 Weight fraction Nanoclay.

Conclusion

Nanoclay reinforced AA 5083 composites for four varying compositions such as 0, 1, 2 weight fraction were developed using stir-casting method. The experimentally tested Nanoclay reinforced AA 5083 composite material was applied in the design during the 3D CAD modelling of solid and round hole perforated type forearm and main arm of the manipulator of the SCARA robot. The simulation was performed in the MATLAB/Simscape Multibody platform linked with the SolidWorks modelling software. The results of Simscape Multibody simulation was observed for various Nanoclay compositions. The comparative study on the torque obtained through simulation reveals that the material used with reinforcement of 2 wt% shows the better torque characteristics in the RSCARA with round hole perforated type manipulator links. The Nanoclay composites can replace steel, aluminium and titanium alloys for robot structural design due to its strength to weight ratio with good damping and torque characteristics. Thus by adopting the methodology proposed in this work Nanoclay reinforced AA 5083 composite material can be applied in the robot development, which will be cost effective and durable. This is the accomplishment result of this novel research.

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