Aluminium–Steel Composite Foam in Joint Dynamic Performance of Redundant Articulated Robot Components

M. Saravana Mohan, P. S. Samuel Ratna Kumar, P. M. Mashinini, and Kahtan Aziz

Abstract This paper investigates the influence of aluminium alloy low carbon (Al-LC) steel composite foam in the joint dynamic property of redundant articulated robot (RAR) by adopting modelling incorporated with simulation methodology. The customized composite foam material is used as design material for RAR components during the SOLIDWORKS CAD model development, which is incorporated with Simscape Multibody simulation tool. The dynamic property, torque exerted at robot joints, is identified by means of Simscape Multibody simulation of system blocks scheme of RAR. The results of Simscape simulation revealed the pertinence of applying Al-LC steel composite foam in designing RAR based on the dynamic property observations.

Keywords Redundant articulated robot · A356 · Al-LC steel foam · Joint dynamic property · Simscape Multibody

1 Introduction

In the robot structural design, the material used influence its static and dynamic properties like strength, stiffness, damping co-efficient, corrosion, wear resistance and joint torque, etc. In the most recent decade, the alloys of aluminium and titanium metal and Polymer matrix composite materials were applied in robots for its development. Aluminium alloys are widely utilized by robot developers for its lesser weight besides its strength to weight ratio, high durability and less cost.

M. Saravana Mohan (✉)
Department of Mechatronics Engineering, Kumaraguru College of Technology, Coimbatore, Tamil Nadu, India
e-mail: saravana.moha@gmail.com

P. S. Samuel Ratna Kumar · P. M. Mashinini
Department of Mechanical and Industrial Engineering Technology, University of Johannesburg, Doornfontein Campus, Johannesburg, South Africa

K. Aziz
School of Engineering and Built Environment, Anglia Ruskin University, Chelmsford CM1 1SQ, UK

K. Rajkumar et al. (eds.), *Recent Advances in Materials Technologies*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-19-3895-5_31

Due to its properties, the investigators applied titanium and 7075 aluminium alloys in the humanoid robot joints and conducted the fatigue study [1]. Likewise aluminium alloy 6061-T6 was applied in the industrial robot parts with mobility for its good resistance to corrosion, workability and low cost to investigate the manipulator performance. The thrive of researchers for new material development paves the way for the evolution of metal foam (MF). The metal foam (MF) is a porous material possess a unique property like high specific stiffness to weight ratio, strength and great damping capacity with high energy absorption. These materials attract wide structural applications such as spacecraft, automobiles, ballistic armour, etc., without affecting the mechanical performance. Compared to other foam type material (example: polymer foam), metal foams are preferable for tough and high-temperature environment, due to its melting point is like the base material [2–4].

The new composite metal foam (CMF) material was developed by means of filling interstitial spaces within hollow spheres of metal matrix. This CMF hollow sphere provides an accurate homogeneous cell shape and size, the matrix material will provide good bonding between spheres and reinforce thin cell walls. This enhances the mechanical and damping properties [5, 6]. These enhanced material properties motivated the authors to assess the dynamic performance of newly developed Al-LC steel composite foam (CMF) material in 7R configuration RAR with multiple tool end effector (MTEE) shown in Fig. 1 utilizing SOLIDWORKS and MATLAB/Simscape Multibody tools [7].

In the recent past simulation-based research works are carried out to study the dexterity of robots for its development [8]. It is studied from the broad literature

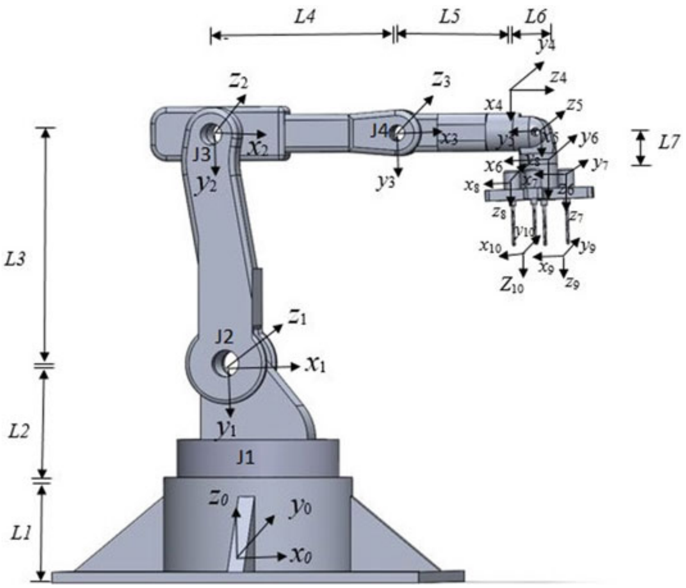

Fig. 1 3D SOLIDWORKS CAD model of RAR

review that modelling and simulation are a path breaking mechatronics approach to analyse various electromechanical system dynamics. This approach augments the development of robotics to encounter the current industrial demand. Designing, testing and predicting the characteristics of robot is essential before fabricating a real-time robot to unravel various technological issues [9]. The simulation methodologies are applied earlier to investigate the dynamic performance of redundant mechanisms [10]. The three dimensional (3D) computer-aided design (CAD) software if integrated with a simulation platform it provides feasible solution to develop various configurations of robots applicable in industrial scenario. MATLAB is the competent simulation tool in the development of robotic systems. If it is interlinked with a modelling platform, it facilities the feasible method of robot development. ABB IRB 140 robot model was developed and simulated using MATLAB and Robot Studio to study the dynamic characteristics [11]. The control features of 6R configuration robot were analysed with the aid of 3D modelling and MATLAB simulation technique [12, 13].

In the MATLAB tool box, Simscape Multibody add-on is an engineer friendly effective simulation tool in developing new configuration of robots. Earlier Simscape Multibody is termed as “SimMechanics”. The CAD modelling and SimMechanics simulation techniques were utilized to analyse the performance of electromechanical systems by well-known authors. SimMechanics simulation already applied in analysing the trajectory and the performance of 6 DOF spatial parallel robots (SPR), two-link planar robot, 3-RRR parallel robot and SCARA [14–16]. KUKA KR5 insertion type robot was developed using Autodesk Inventor to predict the path and motion characteristics by MATLAB/SimMechanics simulation [17]. Similarly, spot welding robot was simulated using SimMechanics [18]. The SOLIDWORKS is an effective 3D CAD modelling software and its integration capability with MATLAB Simscape add-on tools enhances the development of robotic systems. The SOLIDWORKS CAD modelling and Simscape Multibody simulation were carried out in 4 DOF robot used in tea industry and in four axis palletizing industrial robot to study its performance [19, 20].

This is a new attempt, which is not testified hitherto by other researchers. Commonly used industrial robot is called articulated robot. It has RRR Configuration. “R” means Revolute. The non-movable parts are made of steel and movable parts by aluminium. The redundant robotic manipulators are preferable than non-redundant manipulator because of its dexterity and versatility in performing tasks. It is predominantly used in manufacturing industry to perform welding, material handling, drilling, assembly, etc., operations.

In this research work, the influence of Al-LC steel composite foam in redundant articulated robot design has been studied in three phases. In the first phase, 3D CAD RAR was established by incorporating the material property data of the CMF material utilizing the modelling capability of SOLIDWORKS package. In second phase, the multi-body system block diagram (MBSBD) of RAR was generated through transferring the 3D CAD solid model to Simscape Multibody II gen. simulation environment. In the final phase, torque exerted at the joints is acquired through Simscape simulation.

Table 1 Mechanical properties of A356 and Al-LC steel foam material [8]

Material	Density (g/cm^3)	Elastic modulus (GPa)	Tensile strength (GPa)	Shear modulus (GPa)
A356	2.67	36.17	0.165	27.2
Al-LC steel foam	2.41	30	185	22.38

2 Material and RAR Modelling

The 3D CAD model of newly proposed RAR of its kind with MTEE is developed by utilizing the assembly parametric drawing features of SOLIDWORKS software. The proposed RAR manipulator link dimensions are $L1 = 250$ mm, $L2 = 250$ mm, $L3 = 450$ mm, $L4 = 300$ mm, $L5 = 275$ mm, $L6 = 150$ mm and $L7 = 150$ mm.

During the modelling process, the important mechanical properties density, elastic modulus, tensile strength and shear modulus of the chosen design material Al alloy A356 and Al-LC steel composite foam given in the Table 1 are consigned to RAR components.

After the modelling process, the CAD model is exported to Simscape Multibody platform form for simulation via Simscape export link available in the CAD modelling environment.

3 Simscape Multibody Simulation

The multibody simulation is carried out in Simscape Multibody II gen. environment. It is a prominent simulation software platform applicable for developing 3D EMS like robots. The CAD models developed in supporting modelling software in Simscape Multibody compatible file format will articulate and elucidate the multibody system motion. The multibody system will be developed in the form a block diagram in which sequence of blocks represents the bodies, force elements, joints and constraints of the CAD model as shown in Fig. 2. The required model can be parameterize using Simscape expressions and system dynamics can be visualized. The varying structural configuration with improved constraints can be analysed from the results of simulation in reduced time is an important feature of SimMechanics [16]. In this investigation, XML file format is generated from the CAD model of RAR by the changeover of file from SOLIDWORKS modelling to Simscape II gen. simulation platform. By executing XML in MATLAB/Simscape Multibody, the MSBD of RAR was developed. The motion input primitives are consigned to the joint blocks and the dynamic property in the joints is derived as output. The simulation can be viewed through Mechanics Explorer (Fig. 3) and the torque exerted at the joints are illustrated in Figs. 6, 7, 8 and 9.

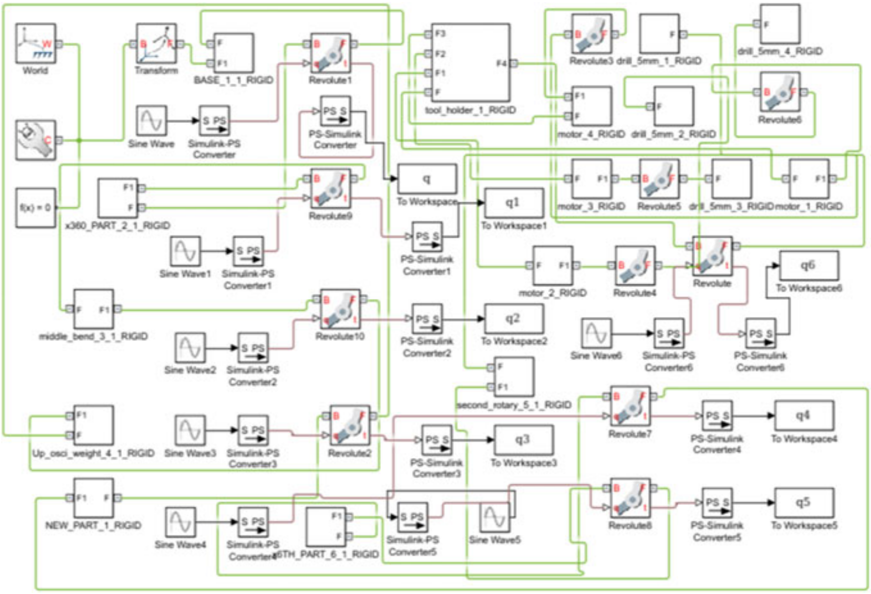

Fig. 2 Simscape Multibody system block diagram with input output joint primitives

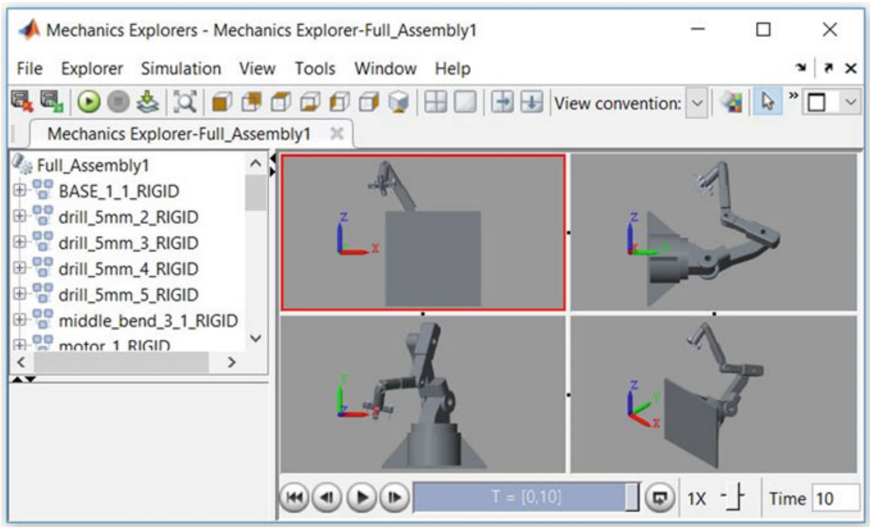

Fig. 3 SimMechanics explorer view of the RAR simulation

4 Simscape Simulation Results

The I/O joint primitives are assigned with the addition sine wave, Simulink-PS and PS—Simulink convertor to I/O of joint blocks of the Simscape multi-body system of RAR accordingly. The joint torque acting for angular displacement 90° in the time period of 10 s is observed through simout blocks as given in the Table 2.

The simulation is monitored through the Mechanics Explorer with the generation of the time versus torque plots as shown in the Figs. 4, 5, 6, 7, 8 and 9. If Al alloy A356 is the design material applied to the components of the robot, torque at joint 1 and joint 2 is 311.4Nm and 2106 Nm is observed by Simscape Multibody simulation, respectively, as depicted in the Fig. 4. Similarly, torque values obtained at joint 3, joint 4, Joint 5, Joint 6 and Joint 7 are 775.6 Nm, 380.4 Nm, 44.17 Nm, 19.44 Nm and 0.59 Nm shown in the Figs. 5 and 6.

The torque exerted at joint 1, 2, 3 and 4 are 275.1 Nm, 1860 Nm, 686.2 Nm and 337 Nm as illustrated in the Figs. 7 and 8, if Al-LC steel foam material is used as RAR design material. Similarly, torque exerted at joint 5, 6 and 7 is 39.37 Nm, 17.35 Nm and 0.562 is shown in Fig. 9.

Table 2 Customized Material Vs Dynamic Performance

Material used	Al alloy A356	Al-LC steel foam	Variation percentage
Joint torque (Nm)			
Joint 1	311.4	275.1	11.65
Joint 2	2106	1860	11.68
Joint 3	775.6	686.2	11.52
Joint 4	380.4	337	11.40
Joint 5	44.17	39.37	10.86
Joint 6	19.44	17.35	10.75
Joint 7	0.59	0.562	4.74

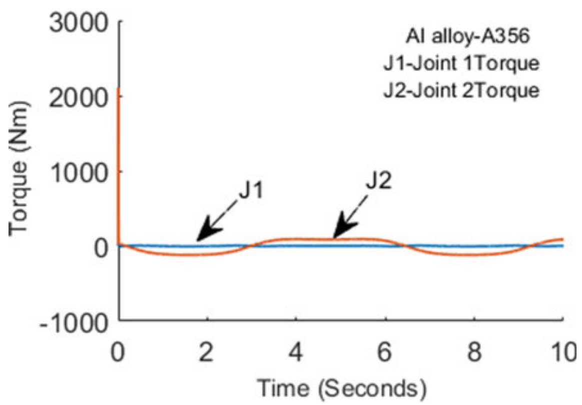

Fig. 4 Torque at revolute joint 1 and 2, if material is Al alloy A 356

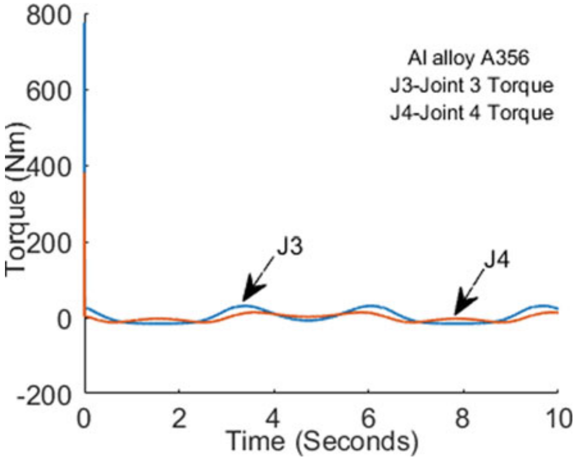

Fig. 5 Torque at revolute joint 3 and Joint 4, if material is Al alloy A 356

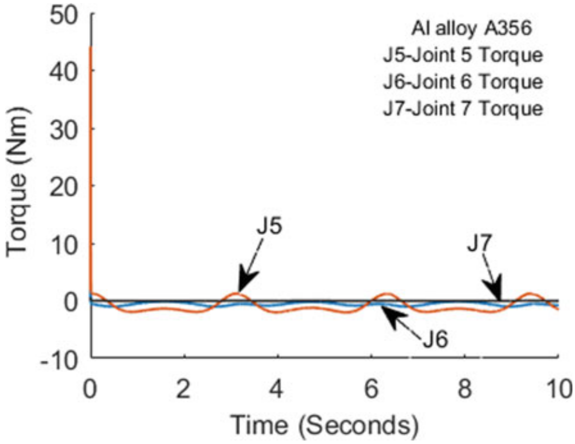

Fig. 6 Torque at revolute joint 5, 6 and 7, if material is Al alloy A 356

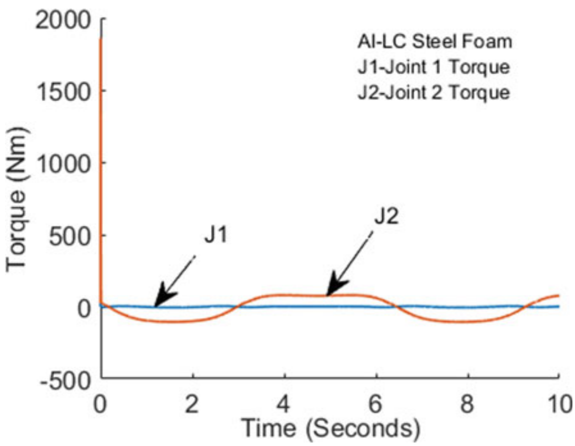

Fig. 7 Torque at revolute joint 1 and 2, if material is Al-LC steel foam

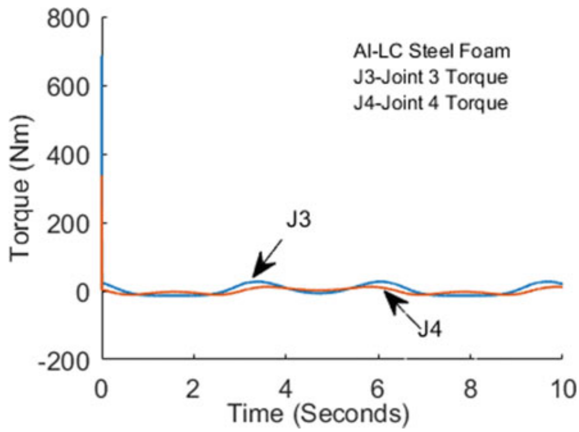

Fig. 8 Torque at revolute joint 3 and 4, if material is Al-LC steel foam

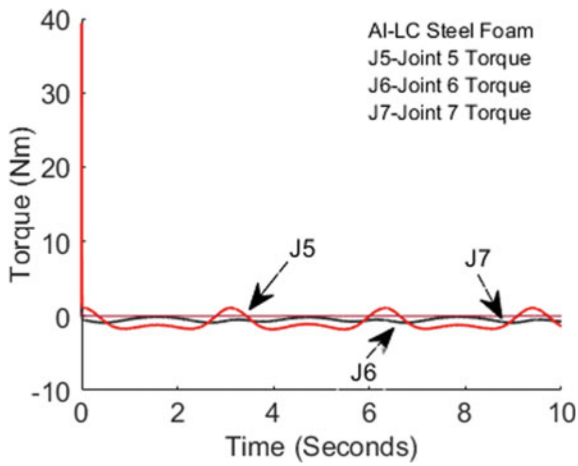

Fig. 9 Torque at revolute joint 5, 6 and 7, if material is Al-LC steel foam

The simulation results infer that the torque acting is relatively less in the RAR joints if the applied design material is Al-LC steel composite foam (CMF). It is due to the CMF material with uniform hollow sphere by accurate cell shape and size provides a unique property like low density, good compression strength, high energy absorption rate and damping ratio. Hence, Al-LC steel composite foam material is inferred as suitable for RAR design.

5 Conclusions

In this research paper, the influence of Al-LC steel composite foam in the joint dynamic parameters of RAR is studied with the aid of sophisticated modelling and multibody simulation methodology. The RAR multibody block system was developed in MATLAB/Simscape Multibody environment by using the compatible converted file format from CAD platform. The Simscape simulation results conclude that the torque experienced in all the joints of RAR is comparatively less, if Al-LC steel composite foam is the RAR design material. This methodology paves the way for further application of Al-LC steel composite foam in the development of different robot configurations in less cost and high mechanical stability.

Acknowledgements The authors are grateful to the Kumaraguru Centre of Industrial Research and Innovation (KC.IRI), the research body of Kumaraguru Institutions, Coimbatore, Tamil Nadu, India for utilizing its state of the art to carry out this research work.

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