Numerical Estimation of Hardness of Carbon Nanotubes reinforced Al metal matrix

Pothamsetty Kasi V Rao, B. Raghu Kumar

Abstract*: *The present study focuses on the numerical estimation of hardness of Aluminum with MWCNT sintered composite by variation of percentage amount of MWCNT's being mixed to the base metal. By applying the rule of mixtures, the physical properties of Al-MWCNT were modeled for conducting the Brinell hardness test numerically. The numerical estimation is based on the explicit dynamics formulations in order to account the short duration and high deformation of the body and nonlinearity. By changing the indentation force applied on the composite specimen, various indented diameters are measured and hardness is calculated. It is found by the observations that for the higher percentages of the MWCNT mixed the hardness of the specimen is also increased proportionally by a trend constant.

Index Terms*: *Brinell hardness test, explicit dynamics formulations, Aluminium, CNT.

I. INTRODUCTION

Aluminum is one of the purest and lightest material ever known by the properties of aluminum which can assert some extend physical loads, but can never be used in high stress environment such as Aerospace, navel and sports and heavy machinery and electronics industries, even with the introduction of 7000 series aluminum with enhanced physical properties of strength and hardness even more enhancement is in demand to incorporate aluminum in many wider areas, because of its ease of manufacturing (extraction and forming) process and its cost. Many researchers are investing into this metal to improve the strength and another physical property by modification in heat treatment process and alloying with higher strength materials. Compositing this material with the sintering using MWCNT (Multi wall carbon nanotubes) has paved a new method of improving the hardness the reason in which MWCNT are chosen because they have good control on the micro structure bonding and reinforcement with the metals and they even exhibit good bulk properties as a single string structure. To achieve this composting the only method available was in powder metallurgy as sintering which composites are fabricated by fusion and heating of powered component here aluminum ball milled powder with MWCNT. This composting by sintering investigated experimentally by (Esawi et al. 2010) has shown that the indentation modulo has been greatly increased changing the amount of MWCNT percentages, well the assertion of adding or composting the aluminum more than 5% of MWCNT has shown an drop in the hardness which is nonlinear in nature, but the positive side of his investigation has given enough strengthen value that can be used in high stress environment.

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II. LITERATURE REVIEW

The experimental study CNT with compositing with the Aluminum to investigate the mechanical by restricting the amount of CNT concentration of 5% has been made first by Esawi et al. 2010 [1].The experimental study of strengthening behavior of Aluminum on compositing with CNT has been investigated by the (George et al. 2005) [2]. The experimental investigation of Aluminum CNT with the well align fiber formulation achieved by the extrusion process has been investigated by the (Kwon et al. 2010) [3]. Mechanical characterization of Multi wall CNT aluminum composites by varying concentration of MWCNT and stress stain experimentation was investigated by the (Narayanan 2009) [4]. The experimental investigation of the hardness value for Al-MWCNT with the varying percentages by using the Brinell hardness formulation have been investigated by the (Girisha & George 2014) [5]. The thermal stability of Al matrix was found to be increased with the addition of carbon nanotube content in the metal matrix [6]. The flexural strength and impact strength of carbon nanotubes reinforced metal matrix was found to be increased drastically [7]. The size as well as weight fraction of carbon nanotubes will influence the thermal properties of carbon nanotubes reinforced Aluminum metal matrix [8].

III. METHODOLOGY

In order to find the hardness, testing has to be made by using Brinell or Vickers or Rockwell procedures but the problem with the testing is the method of finding the hardness is bit destructive i.e. once the indentation made that part of specimen cannot be used again, and even fabricating the composite is cost ineffective so the alternative method is to validate by virtual numerical analysis that is conducted using FEA Formulations. Based on the primary experimental property characterization of density, Young's modulus and passion ratio there of two methodologies available for analyzing the composites

- By modeling the microstructure

- By modeling the Materials based on law of mixtures.

The modeling of microstructure using CAD is a tedious task and since the distribution of fibers are randomly oriented and there is no formulation of modeling this randomness and even by assuming a random noise distribution function (RNDF) and Python coding, the results obtained are subject to case study which take time to correlate with the experimental results and by numerous iterations the time taken to converge the solution is larger and the probability of getting the solution numerically that will match the solution is something in 1/n where 'n' is the number of simulation event by change in random Noise parameter. So, the next best alternative is by modeling the material based on the law of mixtures which is easy and mostly understood.

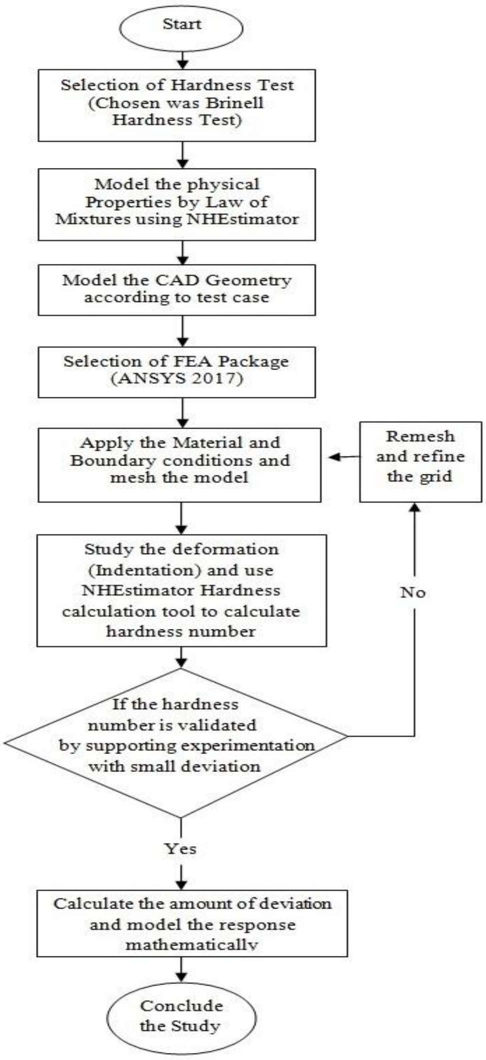

Fig 1: Methodology followed for the study

The material is modeled using the custom made computerized interface called as NHEstimator tool which is capable of modeling of single fiber composites including the MWCNT with special experimental coefficients and also capable of finding the hardness values based on Brinell hardness formulations where some special modifications are made to law of mixtures according to the experimental formulation made in (Esawi et al. 2010) this formulations are inbuilt into NHEstimator where it computes (modeled) the physical properties of the Al-MWCNT composite in terms of values required where these values are provided in the FEA tool for analyzing the hardness phenomena numerically.

IV. FINITE ELEMENT ANALYSIS

The virtual testing is made using the finite element analysis using the explicit formulation. The simulation was made with quarter symmetric i.e. since the indenter and the specimen are in circular cross section this helps in lower the computation complexities and helps in controlled number of nodes and elements. The materials are applied are the varying percentages of Al-MWCNT in order of 0.5%, 1%, 2% and the material of indenter was chosen as steel carbide. With references of material properties described in the in the (Girisha & George 2014) the comparison of finite element analysis results are compared .The boundary conditions of load and fixed supports are applied and the Tet meshing has been chosen for accurate capture of curvatures, the loads applied are of 1000Kgf, the results are iterated until the solution is free from the mesh resolution this is validated by Grid Independence Test (GIT) by increasing the mesh intensity parameters so number of nodes are increased so as the solution too changes but at certain point the solution remains constant even with the mesh intensity changes at this point it is free from mesh.

In order to model the indentation phenomena, the plasticity of the material is to be modeled this helps in defining the penetration, the plasticity is modeled in terms of yield strength and tangent modulus which is a form of hardening plasticity.

Table I: The material applied to the finite element analysis is as follows

S No.	**Density (Kg/m^3)**	**Young's modulus (Pa)**	**Poisson's ratio**	**Yield Strength (Pa)**	**Tangent Modulus (Pa)**
Indenter (Tungsten Carbide)					
1	15880	4.00E5	0.3	--	--
Al + 0.5 Wt % of MWCNT					
2	2700	7.02E10	0.3	8.70E7	5.3E7
Al + 1 Wt % of MWCNT					
3	2610	7.9E10	0.3	9.50E7	5.4E7
Al + 2 Wt % of MWCNT					
4	2680	8.5E10	0.3	9.80E7	6.0E7

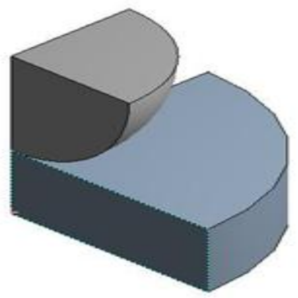

Fig 2: The 3D CAD model modeled to simulate the hardness testing phenomena

The final mesh model for the achieving the appropriate results with the inflation of 5 layers in order to minimize the oxide layers formed by manufacturing this even helps to capture the amount of penetration made from the top of layer. The predefine mesh is disturbed by the inflation by converting it into the Tet mesh (Tetragonal mesh) with face size of 1.5mm.

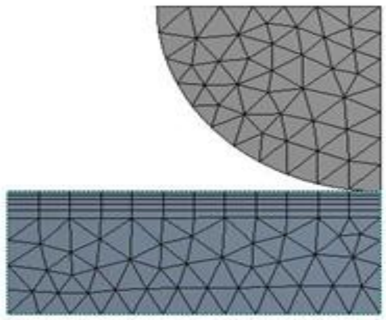

Fig 3: The FEA Model of CAD model with Tet mesh and 5 Layer inflation

The boundary condition applied for testing the hardness is in which fixed supports are added to bottom of the specimen and the force is applied on the top of the surface of indenter since this is a quarter symmetric model the symmetry is also defined which is respective to X- axis and Z-axis. This helps in accurate approximation of the solution.

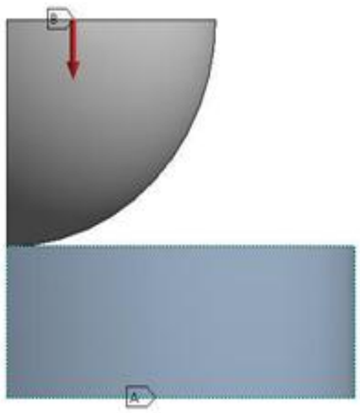

Fig 4: The boundary condition applied to the FEA model with A) as fixed support and B) force applied in negative y-axis

The solution is obtained is observed at the edge of the specimen in order to measure the amount of indentation diameter which is dented by the named selection for the solver

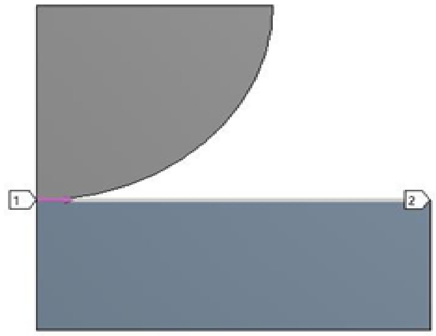

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Fig 5: The solution observation path for the specimen for measuring the penetration along the y-axis

V. RESULTS AND DISCUSSIONS

Table II: The indentation diameters of the various MWCNT percentage specimens are given as follows

S No	Specimen material	Diameter (mm)	Radius (mm)
1	Al + 0.5 Wt % of MWCNT	4.6	2.3
2	Al + 1 Wt % of MWCNT	4.5	2.2
3	Al + 2 Wt % of MWCNT	4.2	2.1

The measured hardness values from the finite element analysis are given as follows. The following calculation are made using the NHEstimatior tool and taken only one-point precision.

Table III: Comparison of measured hardness values and Experimental Hardness Valves

S. No	Specimen	HBN (FEA)	HBN (Experimental)	Deviation
1	Al + 0.5 Wt % of MWCNT	56.5	55	1.5
2	Al + 1 Wt % of MWCNT	59.5	59	0.5
3	Al + 2 Wt % of MWCNT	68.8	69	0.2

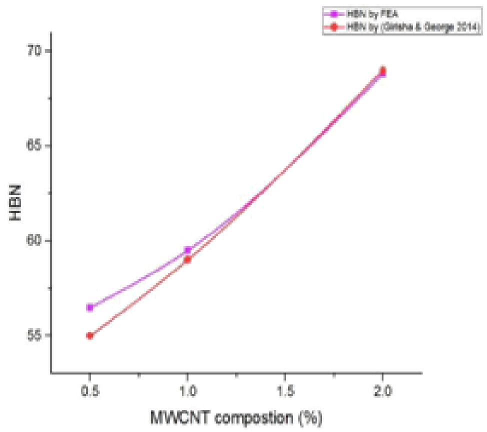

Fig 6: The comparison plot of actual experimental HBN (Girisha & George 2014) and the FEA Results made in the present study

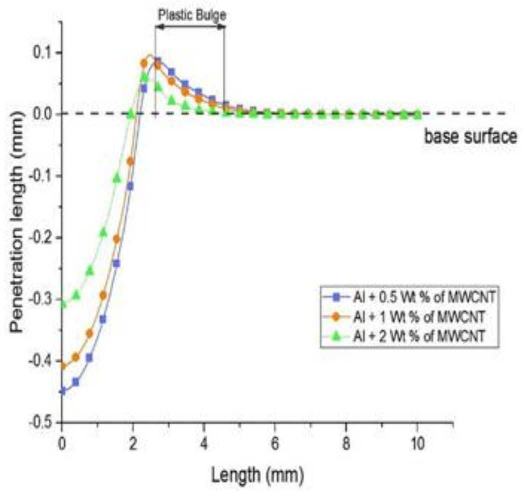

Fig 7: The named selection results by the amount penetrated and the diameter of the indentation made from the FEA study

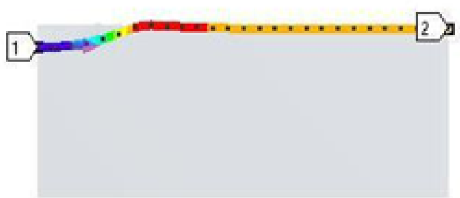

Fig 8: The FEA result of the indentation for Al+0.5 wt % of MWCNT

Fig 9: The FEA results of indentation for Al + 1 wt % of MWCNT

Fig 10: The FEA results of indentation for Al + 2 Wt % of MWCNT

It is found from the above results that there exist some computing error of range 0.2-1.5 which can be neglected and as we can observe from the figure 6 which clearly despise how much the deviation of FEA results have been existed from the measured results, and from the graph which is present in the figure 7 shows as the percentage of the Multi wall Carbon nanotubes got increasing the amount of diameter of the indentation starts decreasing assisting more resistance to indenter.

VI. CONCLUSION

It is observed from the above results, adding the carbon nanotubes percentage by volume to the aluminum metal matrix, the mechanical parameters have been greatly improved and even the hardness is also improved without any actual heat treatment process. It is also observed that the compositing the aluminum with the lower percentages of MWCNT have brought the economic value and retaining the same lighter density. Hence fabricating the nano particles reinforced composites is costlier process and one can rely on virtual numerical analysis to analyze and validate the results.

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