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Experimental Investigations on Friction Stir Processing of Cu-Carbon Nanotubes with Multi-Passes

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Abstract : *FSP has been employed for Cu-carbon nanotube composites successfully and analysed. Further the enahancement of mechanical properties has also been investigated for the composites and found effective for practical applications. The main objective of this paper is to discuss the experimental investigations of FSP of Cu-carbon nanotubes with multi-passes. The effect of FSP parameters such as tool rotational speed, processing speed, axial load, groove width and depth on microstructure and micro hardness investigated.*

Keywords: *Friction stir processing, copper, carbon nanotubes, microstructure, wear, mechanical properties.*

I. INTRODUCTION

Friction stir processing (FSP) was developed for microstructural modification of metallic materials where the tool consists of a shoulder and a pin. One of the main function of the tool is to 'stir' and 'move' the material. Tool rotational speed and feed depends upon the hardness of the material. The main objective of this paper is to discuss the experimental investigations of FSP of Cu-carbon nanotubes. The effect of FSP parameters such as tool rotational speed, processing speed, axial load, groove width and depth on microstructure and micro hardness investigated. Carbon nanotubes were used in the processing and their effect on process parameters of FSP is determined. Microstructure of processed copper with and without Carbon nanotubes in multiple passes are compared.

II. Materials and Methods

Friction Stir Processing Machine

The friction stir processing machine used for the experiment is a hydraulically controlled FSW machine (FSW-4T-HYD). The machine consists of a base which supports the column of the FSW machine which in turn has the spindle head on top. The spindle head harbours the spindle and the motor for running the machine. The elements such as hydraulic clamps, lead screw for the transverse movement of the table and a control unit are provided to hold the work and to control the machine operations. The spindle has provisions for clamping the tool which can be given a tilt angle by tilting the spindle head. Usually a tilt angle of 2º-4º is given (maximum 7º). The table on which the workpiece is clamped can be given a transverse as well as a longitudinal motion. The tool is clamped in the tool head with the help of allen screws. The arrangement for adjusting the RPM of the spindle is provided at the back of the machine. Lead screw provided can be manually adjusted for the transverse movement of the table which in turn allows the adjustment of position of the tool with respect to workpiece. The processing speed of the table can be adjusted manually by rotating the processing speed knob and processing speed is measured manually with a scale fixed with respect to a fixed location on the table. The control unit has the control for switching on or switching off the spindle, clamping switch for controlling the hydraulic clamp, z-axis switch for up and down movement of the spindle head, x-axis switch for controlling the back and forth movement of the table and an emergency off button in case of any mishap.

Friction Stir Processing Machine Specifications
Machine capacity

1) Machine size (LxWxH) : 1300 mm x 1650 mm x 2000 mm
2) Table working surface : 600 mm x 400 mm
3) Machine day light : 950 mm (from floor)

Total weight : 2 ton
Welding material : Mild steel, Aluminium
Job size maximum :
Thickness 5mm
Welding geometry : Straight
Machine Travel

1) X-Axis stoke : 600 mm

2) Y-Axis stoke : 200 mm
3) Z-Axis stoke : 300 mm

Axis thrust force
1) X-axis force : 250 kgf (min) – 2500 kgf (max) (in steps of 50 kgf)
2) Z-axis force : 400 kgf (min) – 4000 kgf (max) (Adjustable in steps)

Motion
1) X-axis feed rate : 0-5000 mm/min
2) Z-axis feed rate : 0-2000 mm/min

Spindle housing
1) Spindle : ISO 40 Taper
2) Spindle speed : 1440 rpm (max)
3) Spindle drive : 11KW/1440 rpm/440V, 3 Phase, AC drive Flange mounting (STARK)
4) Angular contact ball : 7213 - 3Nos
5) Cylindrical roller bearing : NU 2211 EC - 1No
6) Spindle pulley type : Timing pulley

Spindle housing tilting : Angle (-5° to 5°)
Tool holder : ISO 40 Taper – Side lock holder
Spindle nose to table : 300 mm
Z-axis
1) Z-axis drive : Hydraulic operated (Cylinder Φ100x300 mm)
2) LM guide way : Interchangeable Rail (HIWIN) HG R 55 R 780 C- 2nos

Interchangeable Block (HIWIN) HGH 45 CA ZA C U- 4 Nos
3) Linear scale : KA 300/620 mm (SINO)

Y-axis
1) Y axis : 200 mm
2) Y axis slide : Steel strip guide ways
3) Y drive : Manual (lead screw)

Fixture
1) Manual clamping : 1 Set
2) Hydraulic clamping : 1 Set
3) T-slots table : T18x3 mm
4) Block cylinder : A31310-S-V

Hydraulic
1) Hydraulic power motor : 2.2 KW/1440 rpm, 440 V
2) Oil to Oil intensifier : 1 No (pressure booster)
3) Tank capacity : 80 liters

Lubrication
1) Lubrication Pump : Manual pump (Model: H 600-6)
2) Reservoir capacity : 600 CC

Controller
1) PC based control system

Electricals
1) Total connected load : 415V, 50Hz/17 KVA, AC 3 Phase

The experiments have been performed on friction stir processing machine shown in figure1. The experimental work is conducted as per the following steps:
1. Preparation of the work piece and tool
2. Filling carbon nanotube material in the grooves
3. Friction stir Processing
4. Preparation of specimens for tests
5. Tensile, Hardness and microstructure tests conducted

Dimension of the work piece produced are as follows:
Length (mm) 200 mm
Breadth (mm) 75 mm
Thickness (mm) 8 mm

Dimension of groove are as follows:
Depth of cut (mm) 2.5 mm
Width (mm) 1.0 mm

For making the groove of 1mm width, cutter of 1mm thickness is used. Material of cutter is High Speed Steel (HSS). The Tool used for friction stir processing is a Cylindrical Threaded HSS.

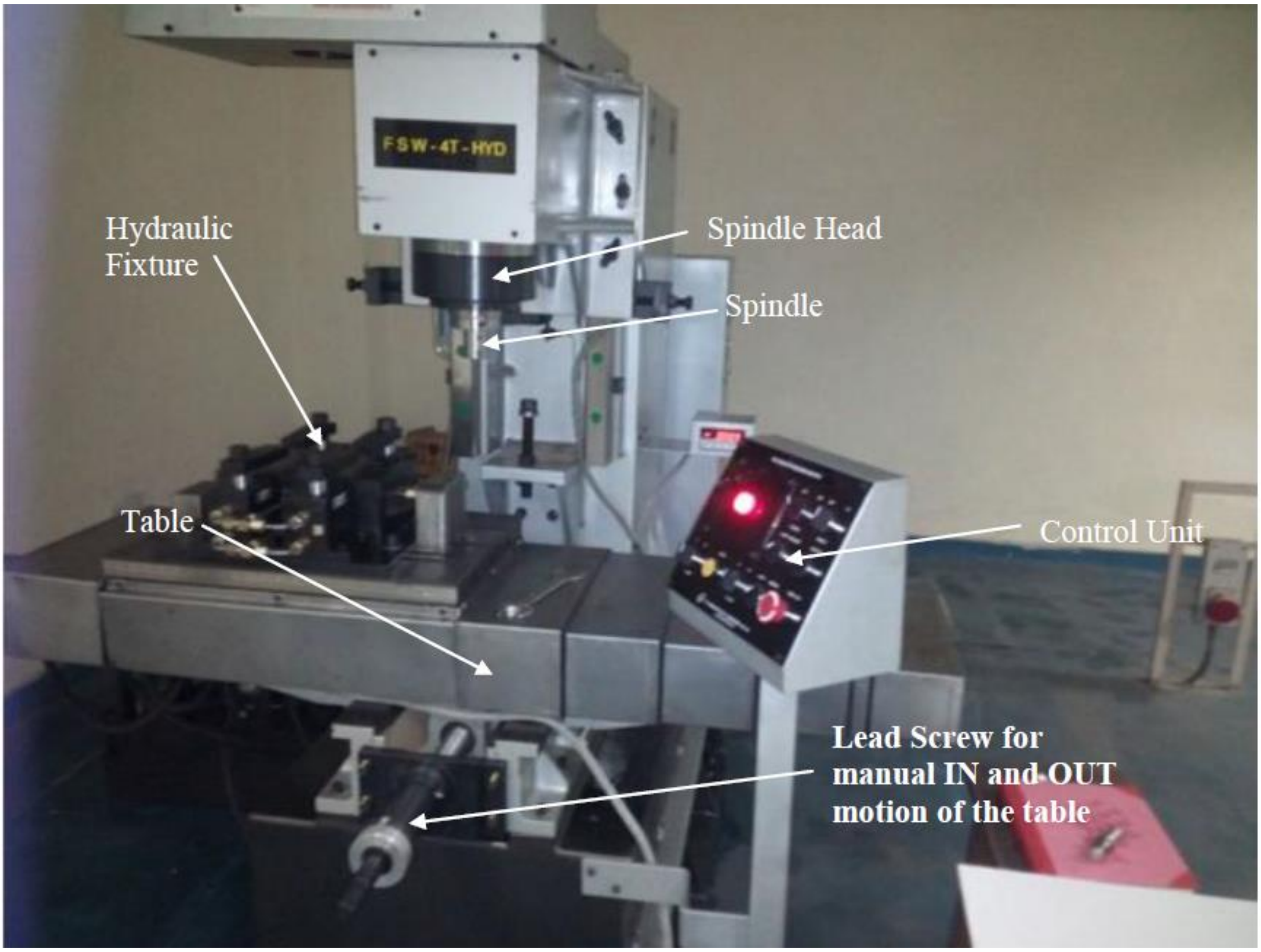


Fig. 1. FSP machine

Fig. 2. Tools used during Friction stir processing

Fig. 3 CNT filled in the grooves of copper plate

Dimension of the tool are as follows:

Length of tool 120mm
Diameter of the tool 19.95mm
Width of the probe 3mm
Diameter of the probe 7mm

Cylindrical threaded tool have certain advantages over the cylindrical tool are as:
1) Better processing results
2) Reduce weld force
3) Enable easies flow of plasticized material
4) Increase interface between the pin and the plasticized material, thereby increasing heat generation.

Properties of Carbon Nano tube are as follows:
Diameter 50-85nm
Length 10-15 micrometer
Nitrogen surface area 10-90 m2/gm
Volume resistivity 2i<< 5*10-4ohm-cm
Carbon content >94%

Advantages of using Carbon Nano tubes in the Processing:
- Develop High Tensile strength in the material upto 63 GPascals.
- Leads to strong interfacial adhesion
- Increases stiffness and strength of the material.

The parameters used during processing are as follows:
Load (Kg) 1000kg
Feed (mm/min) 22mm/min
Rotational speed of tool (rpm) 1100rpm

These parameters are kept constant during the processing. For Analysis of the micro structure and mechanical properties, the processing is done in “Multiple Passes” on the work pieces.
Tensile test determines the strength of the material subjected to a simple stretching operation. The primary use the testing machine is to create the stress-strain graph. The aim of the test is to asses some mechanical characteristics of the testing material. The results of the tensile tests are used in selecting materials for engineering applications. Tensile properties frequently are included in material specifications to ensure quality.
A universal testing machine (UTM) is used to test the tensile strength and compressive strength of the materials. The result of tensile test is shown in table1.

Table 1: Specimen Details and output Results during Tensile Tests

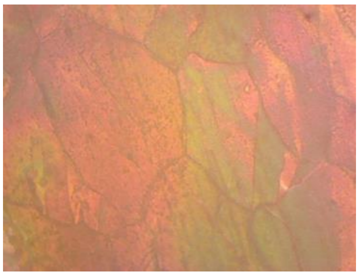
Output(Generic metals tensile from position)	Without processing	Single pass without CNT	Single pass with CNT	Two pass with CNT	Three pass with CNT
Width(mm)	5.98	6.01	6.01	6.01	6.0
Thickness(mm)	5.87	5.81	5.81	5.66	5.79
Gauge Length (initial)(mm)	25	25	25	25	25
Gauge Length(final) (mm)	32.9	46.4	31.5	28.7	29.1
Area (mm^2)	35.1	34.9	34.9	34	34.7
Ultimate Force(N)	8560	6840	2520	2570	4340
Ultimate Stress(MPa)	244	196	72.1	75.5	125
Offset @ 0.2%(N)	7600	4120	1610	2340	3760
Offset @ 0.2% (MPa)	217	118	46.2	68.7	108
TE(Auto)(%)	30.5	91	24.6	13.3	16.0

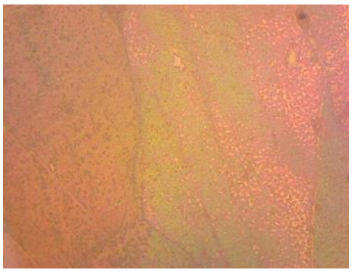
Table 2: Hardness test results

Sr. No.	Specimen	Vickers hardness number (HV0.3)
1.	Base metal	92-94
2.	Specimen Processed without CNT	92-94
3.	Processed with CNT single pass	68-72
4.	Processed with CNT double pass	74-78
5.	Processed with CNT triple pass	88-90

Output result from the hardness test is shown in table 2. Test was performed on Vickers hardness machine. In the above result as the processes increases with multiple passes hardness also increases.


1(a) Specimen at 10x

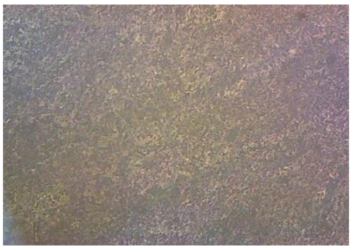

1(b) Specimen at 20x


1(c) Specimen at 50x

Specimen without CNT with single pass-2(a) Specimen at 10x

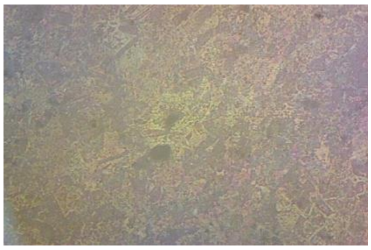
2(b) Specimen at 20x

2(c) Specimen at 50x

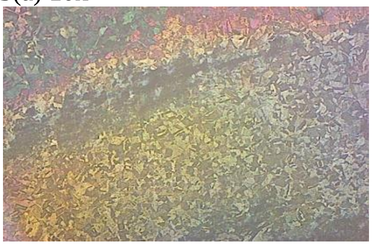


Specimen with CNT single pass-3(a) 10x

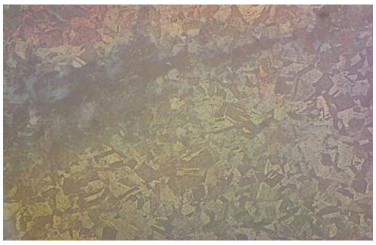
3(b) 20x



3(c) 50x



Specimen with CNT double pass-4(a) 10x

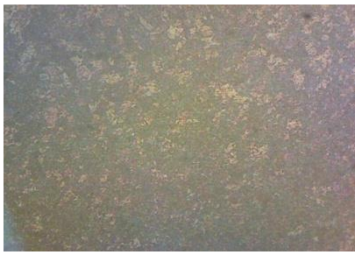


4(b) 20x

4(c) 50x

Specimen with CNT triple pass-5(a) 10x

5(b) 20x



5(c) 50x

Due to multiple passes, the microstructure obtained was found to be more compact because of dispersion of the carbon nano tubes in the composite material very well and grains of the composite material found finer and defect free as number of passes increases.

CONCLUSION

In this study the following conclusions are made on the basis of tests performed:

The ultimate tensile strength of the processed material comes out to be lesser than the parent material.

Hardness of the processed specimens increases as the number of passes are increased due to more compact microstructure. The hardness number comes out to be highest for third pass in comparing with single and double passes.

Microstructure obtained gets more compact and defect free as number of passes increases.

In tensile testing, the ultimate force decreases from 8560 to 6840 N from base material to single pass specimen without CNT. But in case Specimens with CNT with single, double and triple passes the ultimate force increases.

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