# EXPERIMENTAL STUDY ON STRUCTURAL PARAMETERS OF WIRE ARC ADDITIVE MANUFACTURING ON NICKEL BASED ALLOY USING ARGON ARC WELDING

Bandaru KIRAN[1] and Rajyalakshmi G[2,*]

*Although improvement of Additive Manufacturing is growing rapidly, secondary sector is demanding for manufactured samples with large dimensions. Laser Metal Deposition methods are not able to produce samples with required dimensions. In this situation Wire-Arc Additive Manufacturing provides large amount of deposition rates without any size constraints. Hence, WAAM is chosen as the best additive manufacturing for producing the near-net shape mechanical components with good mechanical properties which are used in aeronautical industries like aircraft parts, making efficient and lighter engines. The main aim of this paper was to successfully manufacture a rectangular bar using Wire Arc Additive Manufacturing (WAAM) with ERNiCr-3 as filler material using Gas tungsten Arc Welding (GTAW) through deposition on mild steel plate. Microstructure to be examined for different deposited layers and observe the variation whether any cracks or defects are present to check the sustainability for fabrication of the component. To get Macrostructure images for the clear view of different passes and layers deposited. Wear test results to be studied for the variation of wear depth and Coefficient of friction against time. Scanning Electron Microscopy (SEM) to be carried out to get the surface topography of the component and identification of dendritic and inter-dendritic structures, Energy Dispersive X-Ray Spectroscopy (EDAX) is conducted for identifying the chemical composition of the component and X-Ray Diffraction (XRD) is conducted for identifying the secondary phases in the grains. Hardness test is performed on different layers to check the hardness.*

**Keywords**: Wire Arc Additive Manufacturing; Gas tungsten Arc Welding; Mild steel; ERNiCr-3; Wear depth; Scanning Electron Microscopy; Dendritic and inter-dendritic structures; Energy Dispersive X-Ray Spectroscopy; X-Ray Diffraction; Hardness test; Cold Metal Transfer.

## 1. Introduction

ASTM has given a statement that additive manufacturing is the process for joining metals layer by layer to produce product from 3d data. Additive Manufacturing is emerging as a great alternative for the conventional manufacturing processes. WAAM technologies include plasma welding, MIG welding and GMAW as their investment is lower. WAAM techniques are

[1] Vellore Institute of Technology, India, e-mail: rajyalakshmimed@gmail.com
[2]* Vellore Institute of Technology, India, e-mail: bandarukiran4@gmail.com (corresponding author)

classified by the feed stock type (wire or powder), heat source (laser welding, electron beam welding) and the deposition methods. Heat source type techniques like laser and electron beam welding are very expensive and harmful to the human and environment. Hence, alternative deposition methods like TIG welding is highly suitable for performing WAAM process as this is less contaminant to the environment, low cost and complex parts can be manufactured in less time with low wastage of material. Many industries such as aerospace, medical, transportation, energy and consumer products are looking for more precise manufacturing methods like additive manufacturing.

Complex shaped parts can easily be produced with additive manufacturing and it can produce a single complex part instead of making multiple parts and joining them. It has high rates of deposition, low cost for the equipment and material with accurate integrity of structure. This research paper focuses on wire feed AM of ERNiCr-3, to produce a rectangular bar with good accuracy, surface finish and effective mechanical properties. Additive Manufacturing is more convenient than Traditional Manufacturing as the process replaces conventional processes like forging. Nickel based alloy ERNiCr-3 is selected as filler material for additive manufacturing using Gas tungsten arc welding (GTAW). TIG welding is one among the arc-wire additive manufacturing techniques which uses non-consumable electrode and filler material.

## 2. Literature Review

Studies on AM shows that it can produce parts with complex geometric shapes more conveniently compared to conventional manufacturing process. It has some advantages over traditional manufacturing like design flexibility, reduction in weight, consolidation of part and assemblage. Lidong Wang and Cheryl Ann Alexander, (2016) analyzed that application of additive manufacturing is increasing rapidly in the field of Aerospace, Manufacturing, Automotive and Medical Industry. Nicholas et al, (2013) considered the use of GTAW in additive manufacturing of Ti-6Al-4Y. Experiments were conducted to investigate the influence of common welding process parameters on the geometry of the resulting multilayer deposit.

From the results obtained, the average thickness of the wall type deposit is primarily a function of arc current and travel speed while build-up height is mainly related to wire feed speed, and deposition rate. Jigar R. Parasiya, (2014) studied that GTAW can be used with or without filler material due to which it has a wide variety of applications compared to other welding processes. Tensile properties determined by [R.L.KLUEH, (1980)] for the ERNiCr-3 weld metal within the temperature range of $25^0$c – $732^0$c at strain rates of $3*10^{-4}$/s and $3*10^{-6}$/s. At higher strain rate $3*10^{-4}$/s, there is no much effect on ductility and ultimate tensile strength because yield strength of the smaller weldments was less than larger weldment. And the two types of weld sizes were studied for the effect of workpiece dilution and noticed that more amount of dilution was present in the smaller iron welds. I. Hajiannia, (2013) studied weldability evaluation for dissimilar welds by using ERNiCr-3, ER309L as filler materials. After completion of welding, optical microscopy and scanning electron microscopy (SEM) was conducted. And the results were shown that optimum qualities are provided by filler material ERNiCr-3.

Gas Tungsten Arc welding, otherwise called tungsten inert gas welding is a circular segment welding process that utilizes a non-consumable tungsten terminal to create the weld. The weld region is shielded from atmospherically pollution by a protecting gas and a filler metal is typically utilized. The gear required for the gas tungsten circular segment welding activity incorporates a welding light using a non-consumable cathode, a consistent current welding power supply, and a protecting source. Gas tungsten arc welding has two kinds of polarities in power supply like direct current straight polarity and direct current reverse polarity. Welding different metals frequently acquaints new troubles with GTAW welding, because most materials don't break to frame a solid bond. In any case, welds of divergent materials have various applications in assembling. An effective filler rod is chosen which is of same or different in composition from the base plate that increases the mechanical properties of the welded sample.

Additive manufacturing is more convenient than traditional manufacturing as complex shaped parts can easily be produced with low material waste. It provides high deposition rates, low material costs and suitable to replace manufacturing from large forging. Using this, we can make a single component instead of making multiple components. The nickel alloys resist high pressures and temperatures, making them well-suitable for high-performance applications. Hence, nickel based alloy ERNiCr-3 is used in this project work.

From the literature reviewed, there is no work present on Additive Manufacturing using ERNiCr-3. In research on elevated temperature tensile behavior of ERNiCr-3, observed that it has high ultimate tensile strength and ductility, so it can be used to replace with any other material for manufacturing a component.

## 3. Methodology

Advanced CMT (Fronius TransPuls Synergic 4000) power source and an automatic wire feeder were used for the current work can be seen from Fig.1. The CMT welding process is carried out based on the combination arc with negatively and positively poled CMT cycles. CMT advanced welding process possess significant advantages like targeted heat input, high weld deposition rate with no increase in heat input. Cold Metal Transfer is a welding technique performed by a welding robot which detects a short circuit and sends a signal to the system and provides sufficient cooling time before each weld drop get placed.

Filler wire ERNiCr-3 of diameter 1.6mm (seen in Table 2), wire feed nozzle, drill bit and fixture were selected for the process. 99.99% argon was applied as shielding gas and the gas flow is 25 L $min^{-1}$. The nozzle got drilled using drill bits to increase its diameter from 1.4mm to 1.6mm as required for feeding of filler wire. Mild Steel plate of dimensions 150mm*150mm and thickness of 16mm was used as substrate material. The substrate surface was cleaned for removing impurities using steel brush and acetone before processing and the dried filler was used. The Experimental parameters were shown in Table 1.

During deposition, after each and every layer temperature was measured using temperature gun to avoid the bending of the substrate plate. The welding defects such as cracks and pores after welding were determined using X-ray Non Destructive Testing (NDT) and metallographic analysis. The samples for metallography were prepared using wire EDM having dimensions 20mm*9mm are cut from one side of the component was polished with sand paper and disc polishing is done (seen in Fig 2 and 3). Micro metallographic sample was grinded by abrasive paper, and then polished and corroded.

For microstructure test the polish sample was etched by electrolytic process using oxalic acid (10g) and water (100ml). After etching macrostructures were taken to see the clear view of the deposited passes and layers. The samples for SEM, EDAX, XRD and Wear test were performed for the structural changes. Vickers Hardness test was performed throughout top to bottom layers of the sample to study the changes occur because of deposition. The main welding parameters which were required for deposition are shown in the Table 1.

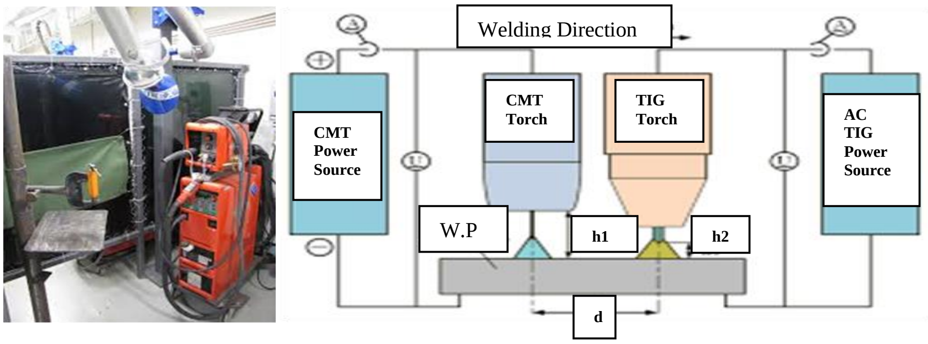


Fig 1. Advanced CMT Power source equipment

*Table 1*

**Welding parameters for deposition**

| Parameters | Value | Units |
|---|---|---|
| Current | 130 | A |
| Voltage | 11.1 | V |

| | | |
|---|---|---|
| Welding speed | 60 | mm/min |
| Wire feed rate | 400 | mm/min |
| Gas | 14.5 | L/min |
| Welding distance | 135 | Mm |

*Table 2*

**Chemical Composition of ERNiCr-3**

| Element | Ni | Cr | Fe | Mn | Al | Ti | Nb | C |
|---|---|---|---|---|---|---|---|---|
| ERNiCr-3(wt%) | 73.11 | 19.59 | 0.75 | 2.95 | 0.27 | 0.43 | 2.42 | 0.1 |

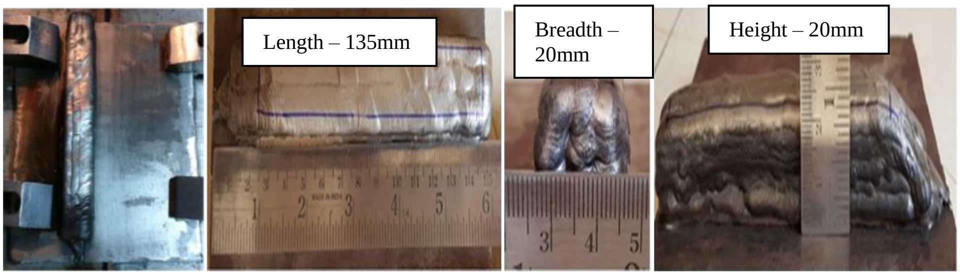


Fig 2. Measurements after deposition

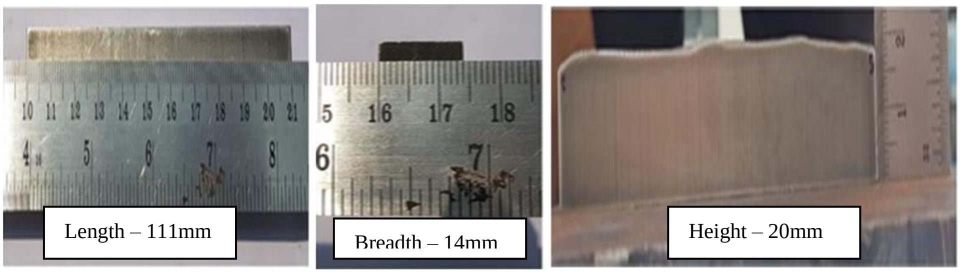


Fig 3. Measurements after cutting

## 4. Results and Discussions

### 4.1 Macrostructure Analysis

The Fig. 4 (a) shows the side Macrostructure (length 9mm and height 20mm) of the deposited material (ERNiCr-3). The 11 layers are clearly visible in the picture. The (b) shows the Cross-section Macrostructure (length 14mm and height 20mm) of the deposited material (ERNiCr-3). The 3 passes for each layer (11 layers) are clearly visible in the picture.

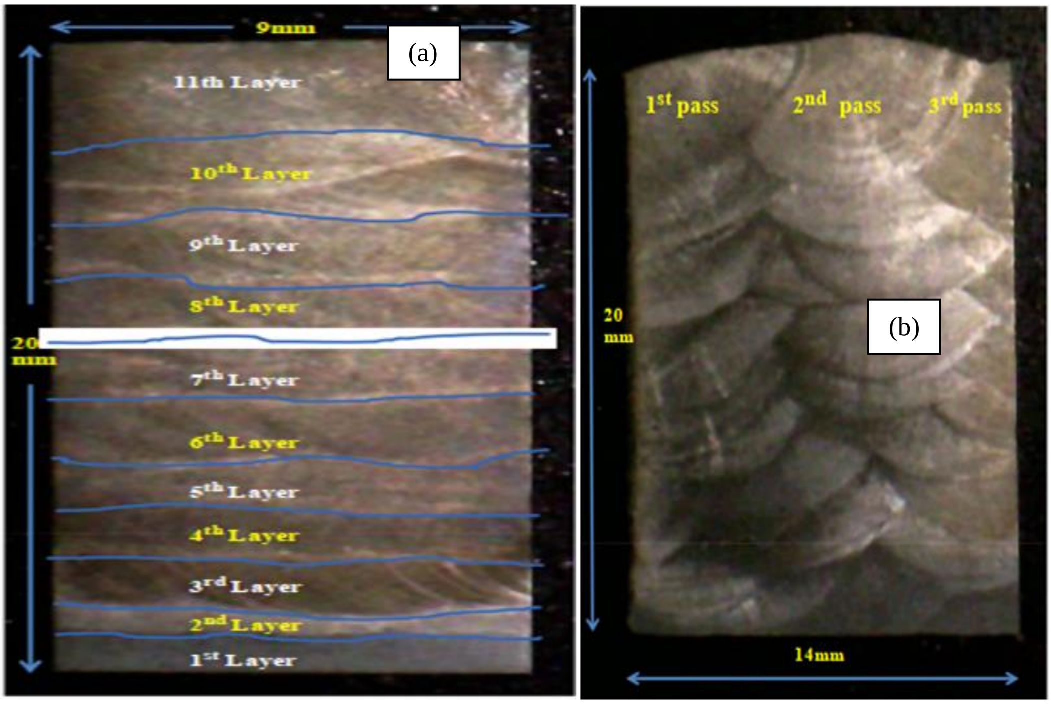


Fig 4. (a)Macrostructure of side showing layers (b) Macrostructure of the passes

### 4.2 Microstructure Analysis

The sample of rectangular shape is cut from a side of component which is made through deposition of eleven layers. The dimension of the sample is 20mm*9mm and having thickness of 2mm. The microstructure analysis of the sample (Fig 5) helps in providing the information regarding the variation in the micro structural properties from bottom ($1^{st}$) to top ($11^{th}$) layer. The microstructure examination through optical microscopy shows the defect and crack free deposition which indicates the component fabrication suitability. By observing the microstructures, the presence of cellular and columnar structures can be identified in some of layers deposited whereas equiaxed structure is found in layer 2 and 3. At the surface of the specimen, as there is a heterogeneous nucleation taking place for few layers equiaxed grains are formed. Cellular structures are present in layers 1, 4, 5 and 11 and columnar structures in layers 6,7,8,9 and 10 formed is justified by thermal gradient. Columnar structures are used to grow where ever more thermal gradient is present. As the thermal gradient direction at solid-liquid interface changes continuously, so the new grains are lean to grow in the orientation which is favorable. So, the individual growth of the grains is fast within short distance, it allows more number of grains to grow, which results in the refinement of grain. Mainly, the solidification can lead to formation of two types of grain structures i.e, columnar and equiaxed. The growth of the grains proceeds equally in all directions when the nucleation of Crystals in an under cooled isothermal melt is over, as the microstructures formed in layers 2 and 3(equiaxed).

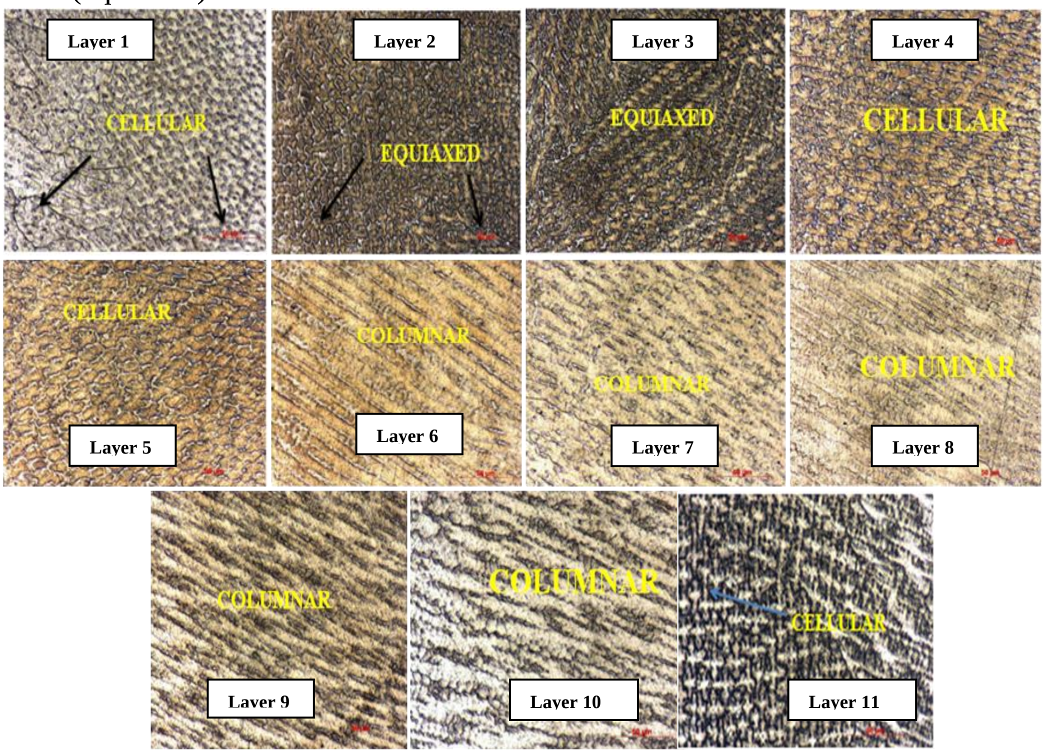


Fig. 5 Microstructures of weld deposition layer by layer

### 4.2.1 Microstructure of the Cross Section of weld samples

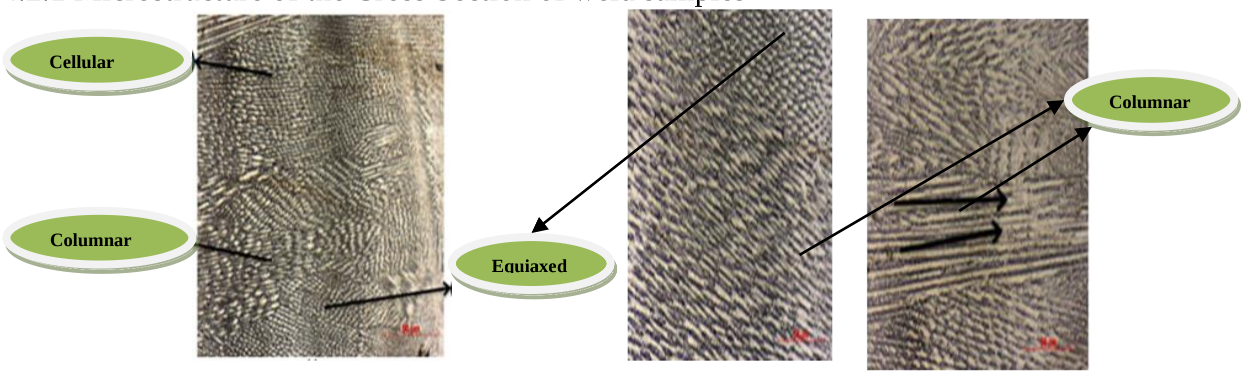


Fig. 6 Microstructure of Cross-section of deposited ERNiCr-3 filler material
(a)full microstructure (b)centre region of the pass (c) inter-pass region

### 4.3 SEM / EDAX Analysis

SEM and EDAX has been done for assessment of segregation in the micro level of the deposited sample. The Fig.7 indicates the SEM micrograph for layers deposited through GTAW with high magnification. Fig 8 shows the EDAX analysis for dendrite and interdendrite structures. The Table 3, 4 shows the chemical composition of dendritic and inter-dendritic region measured by EDAX analysis. So, it can be concluded that the chemical composition around the dendritic region is almost similar to the composition of filler wire used but for inter-dendritic region Cr and Ti composition got increased and chromium carbide is formed because of precipitation.

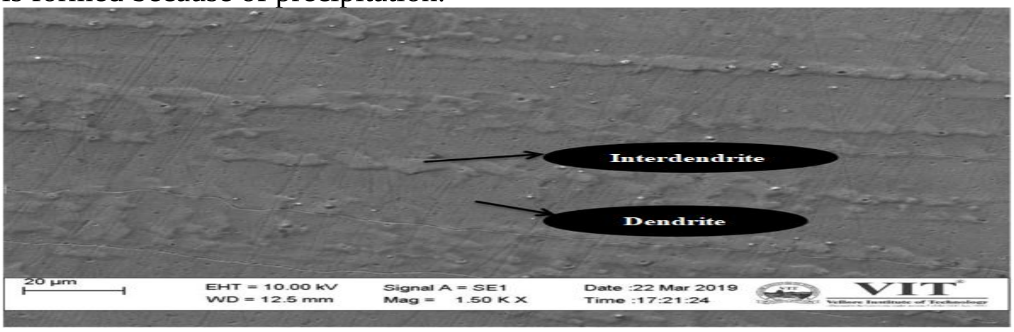


Fig. 7 SEM which shows Dendrite and Inter dendrite structures

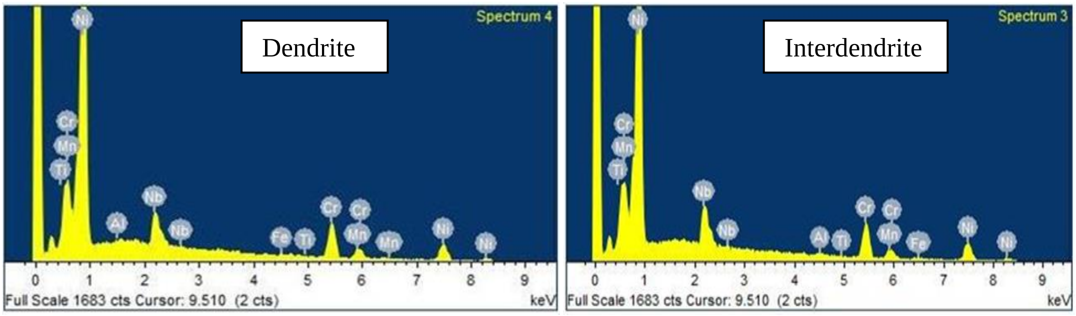


Fig. 8 EDAX analysis for Dendrite and Inter dendrite structures

*Table 3*

**Chemical Composition of Dendrite**

| Element | Ni | Cr | Al | Ti | Mn | Nb | Fe | Total |
|---|---|---|---|---|---|---|---|---|
| ERNiCr-3(wt%) | 71.92 | 15.84 | 0.06 | 0.13 | 4.33 | 4.27 | 3.44 | 100 |

*Table 4*

**Chemical Composition of Interdendrite**

| Element | Ni | Cr | Al | Ti | Mn | Nb | Fe | Total |
|---|---|---|---|---|---|---|---|---|
| ERNiCr-3(wt%) | 60.32 | 22.65 | 3.24 | 2.52 | 2.17 | 6.73 | 2.37 | 100 |

### 4.4 XRD Test

To find the existence of secondary phase of the sample, XRD test is conducted on the sample. The XRD analysis results are shown in Fig.9. EDAX analysis is well supporting the XRD analysis results obtained in the present investigation. In case of ERNiCr-3 sample, the presence of Cr23C6, Ni3Ti and Ni8Nb are observed.

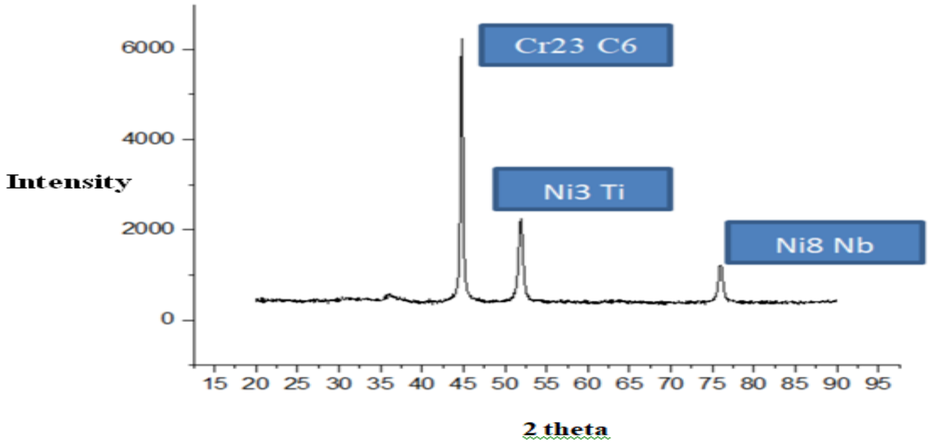


Fig. 9 XRD plot of secondary phase

### 4.5 VICKERS Hardness Test

The sample has been tested with the load of 300 g. The hardness values are shown from the top layer to the bottom layer of the sample. 76 readings are taken in x-direction with distance of 0.25mm each for 19mm. The average value of hardness is found to be 14.9HRC. The hardness values are shown in below Fig.10.

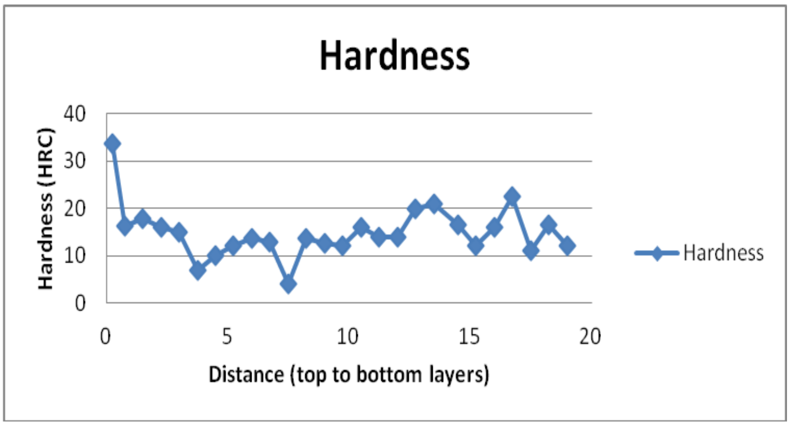


Fig. 10 Hardness (HRC) graph

### 4.6 Wear Test

To evaluate the wear performance of the material the test is conducted in material point of view. The test is performed on the reciprocating wear testing machine were ball is used in the process. The different parameters used in the wear test are mentioned in Table 5.

Fig.11 Component after wear test

*Table 5*

**Wear test values**

| No | Time(sec) | COF | Wear Depth | Temp($^0$c) | Load(Kg) | Speed(RPM) |
|---|---|---|---|---|---|---|
| 1 | 0.053 | 0.002 | 0.403 | 36.438 | 20.072 | 35.359 |
| 2 | 3.157 | 1.595 | 18.257 | 36.223 | 20 | 608.776 |
| 3 | 8.517 | 1.59 | 88.549 | 36.389 | 19.569 | 608.388 |
| 4 | 13.517 | 1.626 | 132.82 | 36.762 | 19.734 | 609.067 |
| 5 | 18.517 | 1.872 | 150.58 | 37.762 | 19.704 | 609.387 |
| 6 | 23.522 | 1.923 | 180.36 | 37.485 | 19.727 | 608.447 |
| 7 | 28.523 | 2.05 | 215.4 | 37.705 | 19.653 | 609.014 |

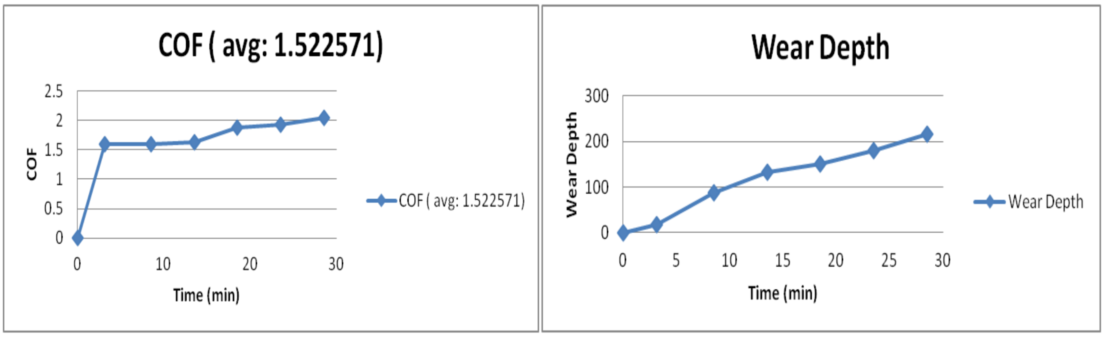


Fig. 12 Wear test graphs for (a)COF and Time (b) Wear depth and Time

### 4.7 Chemical Composition Test

The chemical composition test is performed after the deposition of material to compare with the composition of filler material.

*Table 6*

**Comparison of chemical composition of material**

| Elements | ERNiCr-3(wt%) | ERNiCr-3(after deposition) |
|---|---|---|
| Ni | 73.13 | 73.13 |
| Cr | 19.59 | 20.10 |
| Fe | 0.75 | 1.10 |
| Mn | 2.95 | 2.80 |
| Al | 0.27 | - |
| Ti | 0.43 | 0.236 |
| Nb | 2.42 | 2.27 |
| C | 0.1 | 0.008 |
| Si | 0.38 | 0.062 |
| S | - | 0.002 |
| P | - | 0.001 |
| B | - | 0.002 |

## 5. Conclusion

The macrostructure of the sample from the side of the component shows the 11 layers of deposition of material and the sample from the cross section of the component shows the deposition of three passes from every layer. The microstructure examination of the samples from side and cross section of the component using optical microscopy reveals the defect and crack free deposition which indicates the component fabrication suitability. For all the 11 layers deposited the variation in microstructure for each layer is observed i.e. cellular, equiaxed and columnar. SEM / EDAX results show that the chemical composition in the dendritic region is almost similar to that of filler material but for inter dendritic region the Cr and Ti composition has increased because of precipitation. XRD results are well supporting the EDAX test and shows the compounds formed at the peaks because of precipitation i.e. Cr23C6, Ni3Ti and Ni8Nb. By observing the hardness test which was taken throughout all the layers shows approximately similar values (average 14.9HRC) of hardness for each layer.

Wear test gives the relation between the coefficient of friction, war depth against time. the average coefficient of friction (COF) from the graph is found to be 1.522. Chemical composition test for the sample shows almost the same values as mentioned in the original filler wire material. So, it can be said that after forming the component through deposition of filler material the chemical composition is not varying.

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