



International Journal of Innovative Research in Science Engineering and Technology (IJIRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



Impact Factor: 8.699

Volume 15, Issue 1, January 2026

Processing and Mechanical Performance of Additively Manufactured AISI 347 Stainless Steel Samples

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ABSTRACT: Image inpainting is the process of restoring the lost or damaged regions or modifying the image contents imperceptibly. It refers to the process of filling-in missing data in a designated region of the visual input. In this paper, the technique presented is for detection and removal of text from images. The system detects text using morphological operations, connected component labelling and a set of selection criteria which helps to filter out non text regions. So, the resultant image is the image with only texts. Text Inpainting is done in two steps. The first step detects the text region automatically, without user interaction and in the second step; the text is removed from the image using exemplar based Inpainting algorithm.

KEYWORDS: Fabrication of WAAM samples, Sample preparation for wear test, Wear testing by pin on disc, SEM testing and comparison of results.

I. INTRODUCTION

Additive manufacturing also known as 3D printing, is the process of creating three-dimensional objects by adding layers of objects on top of each other. It is a revolutionary manufacturing process that allows complex and special products to be created with great precision.

In conventional manufacturing, the product is usually produced by removing material from the mass or shaping it by molding or casting. Additive manufacturing builds products layer by layer based on a digital model or design. Additive manufacturing is a layer-by-layer fabrication process that typically involves several key steps. Initially, a three-dimensional (3D) model of the component is created using computer-aided design (CAD) software or obtained by reverse engineering through a 3D scanning process. The digital model is then processed using slicing software, which divides the geometry into a series of thin horizontal layers, each representing a cross-section of the final part. Once slicing is completed, the system is prepared for fabrication by selecting appropriate materials and configuring the 3D printer parameters such as printing temperature, build speed, and layer thickness. During the printing stage, the printer fabricates the component by depositing or solidifying material layer by layer according to the sliced data. Depending on the type of 3D printer used, different fabrication techniques may be employed, including extrusion of molten thermoplastics, sintering or melting of metal powders, or curing of liquid photopolymer resins using ultraviolet light. After printing, post-processing operations are often required to achieve the desired surface quality and dimensional accuracy, which may include removal of support structures, cleaning, polishing, or other surface finishing treatments based on the application requirements.

Additive manufacturing has many advantages over traditional manufacturing. It provides greater design freedom by enabling the creation of complex geometries and internal processes that would be difficult or impossible with other technologies. It also reduces waste as only essential materials are used, unlike traditional manufacturing processes where excess material is discarded.

In addition, additive manufacturing enables rapid prototyping because products can be produced, modified and printed quickly without expensive equipment. This makes it an important tool for production, research and innovation.

In addition, it is possible to determine production and reduce transportation costs and working time by allowing equipment to be as close to the point of use as necessary.

Additive manufacturing encompasses various technologies based on the method of material deposition and solidification. Stereolithography (SLA) is an early and widely used technique that employs a laser or ultraviolet (UV) light to cure liquid photopolymer resin layer by layer, producing parts with high dimensional accuracy and smooth surface finish, making it ideal for intricate and small components. Selective Laser Sintering (SLS) utilizes a high-power laser to selectively fuse powdered materials, typically polymers or metals, where the surrounding unfused powder acts as a natural support structure, enabling the fabrication of complex and functional components. Fused Deposition Modelling (FDM) is one of the most commonly adopted additive manufacturing processes, in which thermoplastic filament is extruded through a heated nozzle and deposited layer by layer; its low cost, simplicity, and capability to produce large and durable parts make it widely popular. Digital Light Processing (DLP), similar to SLA, uses a digital light projector to cure liquid resin across an entire layer at once, resulting in faster build times, although with slightly reduced resolution compared to laser-based systems. Direct Metal Laser Sintering (DMLS) is a metal-specific additive manufacturing technique that uses a high-energy laser to selectively fuse metal powder particles, producing dense components with excellent mechanical properties. Binder spraying, also known as binder jetting, involves selectively depositing a liquid binder onto layers of powder materials such as metals, ceramics, or sand, where the binder acts as an adhesive to bond particles together; the printed parts generally require post-processing steps such as curing or sintering to achieve the required strength

Wire Arc Additive Manufacturing (WAAM): is an additive manufacturing process that uses an electric arc to melt and melt metal wire to build parts layer by layer. It is a metal-based additive manufacturing process with many advantages and especially designed for large metal products. [21-24]

II. LITERATURE SURVEY

AISI 347 metallurgy and baseline wear behaviour

AISI 347 is an austenitic, niobium-stabilized stainless steel designed to limit intergranular carbide precipitation and retain corrosion resistance at elevated temperatures. Variability in microstructure and mechanical behaviour can occur between production batches and manufacturing routes, influencing hardness, work-hardening and surface responses under tribological loading. Surface treatments (e.g., nitriding) have been shown to improve wear resistance for conventionally manufactured AISI 347 by increasing surface hardness and altering tribo-layer formation pathways.

Wire Arc Additive Manufacturing of Stainless Steels

Wire arc additive manufacturing (WAAM) has been considered as a promising technology for the production of large metallic structures with high deposition rates and low cost. Stainless steels are widely applied due to good mechanical properties and excellent corrosion resistance. Additive manufacturing (AM) techniques adopt layer-by-layer accumulation with the aid of CAD/CAM model to develop three dimensional (3D) products. The research has been carried out in materials such as aluminium, AISI 304.

Wire arc additive manufacturing (WAAM) is a process that involves the use of an electric arc to melt and deposit metal wire in a layer-by-layer fashion, ultimately building up a three-dimensional (3D) object. It is a type of metal additive manufacturing or 3D printing technique that utilizes wire as the feedstock material instead of powder or liquid. [13]

Producing stainless steel samples using WAAM

Wire arc additive manufacturing (WAAM) has been considered as a promising technology for the production of large metallic structures with high deposition rates and low cost. In this paper we go through about the chemical composition of AISI 347 and the process parameters required for additive manufacturing. The process parameters in this paper were selected by using trial and error method and the suitable parameters with best results were considered at the end. These process parameters were Further used by us to prepare the samples by WAAM by only modifying the wire diameter

which is given as the input for WAAM procedure. This research paper also helped us in conduction of SEM and XRD analysis on our samples. [14]

Material Characterization techniques

Materials Characterization is an important process in which a material's chemical, microstructure and physical properties are probed, measured and determined using a variety of analytical methods, techniques and tools. a broad group of analytical procedures used to evaluate chemical and physical make-up of any materials. It is different from material testing in that it focuses on fundamental characteristics rather than applied or utility properties. Presents commonly applied characterization techniques in material science along with their advantages and disadvantages. Discusses physicochemical and electrochemical nature of materials including analyses of morphology. Highlights the use of coupled characterization techniques for characterization and biosensing. Understanding of different material characterization techniques such as (XRD, SEM, Porosity, etc.). How these are helpful in understanding material properties and implementation of these on AISI-347 samples produced by WAAM and casting. [15]

Wear behaviour of stainless steel

stainless steel demonstrates remarkable resistance to wear because of its distinctive microstructure and composition. The formation of a protective oxide layer on the surface of stainless steel inhibits corrosion and minimizes wear. The presence of chromium in stainless steel augments its hardness and strength, providing resistance against abrasion. Moreover, researchers have found that subjecting stainless steel to different heat treatment methods can enhance its wear resistance.

The wear behaviour of stainless steel is highly regarded due to its excellent properties. Stainless steel exhibits a favourable combination of hardness, strength, and corrosion resistance, making it a preferred material in many applications where wear resistance is crucial. One key factor contributing to the wear resistance of stainless steel is its unique microstructure. Stainless steel is composed of iron alloyed with chromium, which forms a passive oxide layer on its surface. This oxide layer acts as a protective barrier, preventing direct contact between the steel and the environment. As a result, the stainless steel is less prone to corrosion and wear, ensuring its durability in various conditions. The chromium content in stainless steel plays a vital role in enhancing its wear resistance. The presence of chromium increases the hardness and strength of the steel, making it more resistant to abrasion. The chromium atoms create a solid solution within the iron matrix, altering the crystal structure and providing additional strength to the material.

Furthermore, stainless steel can undergo various heat treatments to further enhance its wear resistance. Processes like annealing, tempering, or quenching can modify the microstructure of the steel, optimizing its mechanical properties. These heat treatments can refine the grain structure, increase hardness, and improve the overall wear resistance of stainless steel. [16]

Wear Testing by pin on disc apparatus

There parameters which influences wear such as: fracture toughness, type of crystalline structure and the occurrence of hard precipitate in the metallic matrix and also its nature. In the present investigation, the wear mechanisms acting in tool steels were analysed and, by normalized tests, wear resistance performance of nine different types of tool steels were evaluated by pin-on-disc testing. Conventional tool steels commonly used in tooling such as AISI H13 and AISI A2 were compared in relation to tool steels fabricated by sintering process such as Crucible CPM 3V, CPM 9V and M4 steels.

This work helped in understanding how pin on disc apparatus is used in wear and friction tests in steel tools. Our research focuses on 347 grade stainless steel. The conduction of wear behaviour testing using pin on disc apparatus was understood with the help of this paper. [17]

III. MATERIALS AND METHODS

The samples were prepared from AISI-347 steel one sample was produced by casting and other by WAAM. The chemical composition of the AISI-347 steel is as follows Table 3.1 shows the chemical composition of AISI-347.

ELEMENT (WAAM 347)	% WEIGHT COMPOSITION
Fe	0.06C
Cr	19.80
Si	0.42
Ni	10.20
Mo	0.75
Cu	0.23
P	0.025
Mn	1.65
S	0.03

The investigation of the wear behaviour of stainless steel samples involved a systematic sequence of experimental steps, beginning with an extensive literature survey and concluding with microstructural analysis of the worn surfaces. Initially, a comprehensive literature survey was conducted by reviewing previously published research articles and technical reports to understand the existing state of work and to identify research gaps relevant to the present study. Subsequently, two sets of samples were prepared for comparative evaluation: conventionally cast stainless steel samples obtained from Mishra Dhatu Nigam Limited (MIDHANI) and additively manufactured samples produced using the Wire Arc Additive Manufacturing (WAAM) process. The fabricated WAAM samples were brazed and welded to form circular attachments on the sample surface to facilitate proper mounting during wear testing. Prior to wear experimentation, both cast and WAAM samples were carefully prepared through surface grinding and polishing to ensure uniformity and reliable test results. Fine surface finishing was achieved using emery papers of varying grit sizes followed by polishing with diamond paste and velvet cloth. Wear behaviour was then evaluated using a pin-on-disc tribometer, where parameters such as wear rate and coefficient of friction were measured. Finally, scanning electron microscopy (SEM) was employed to examine the worn surfaces of the tested samples, enabling detailed observation of surface damage, wear mechanisms, and microstructural irregularities, and facilitating a comparative analysis of the wear performance between cast and WAAM-fabricated stainless steel samples.

IV. EXPERIMENTAL RESULTS

Looking at SEM image of casted sample Fig 4.1, we can find many deformities on the surface of the sample like pits, cracks and oxide layers formed which indicated that surface properties of the sample is not so good and improvement has to be made to improve the surface properties for better results when used in different applications.

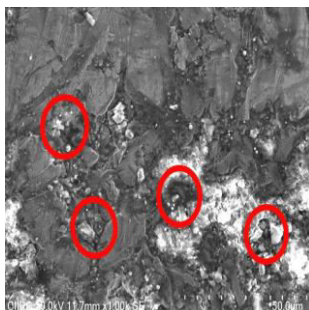


Fig 4.1

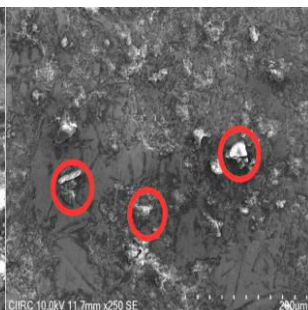


Fig 4.2

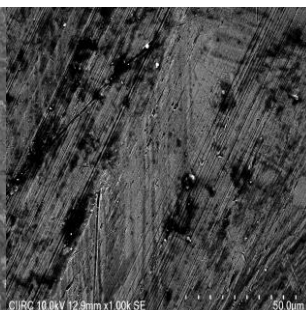


Fig 4.3

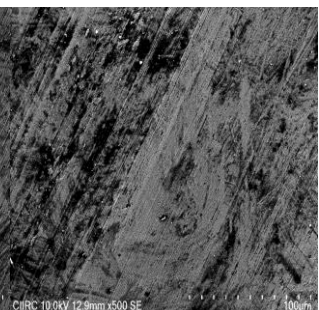


Fig 4.4

Again, from Fig 4.2 at 50.00μ cracks and pits can be observed more clearly and also the oxide layers formed are seen more clearly confirming their presence. The clarity is improved by increasing the scale.

From Fig 4.3 presence of oxide scale and cracks and some other deformities can be found the type of deformities can be detected at higher magnifications and also using EDX the elements which are causing the deformities and other reasons can also be found.

From the Fig 4.3 and Fig 4.4 the surface SEM image of WAAM sample can be seen at 50.00 μ and 100.00 μ which shows not much surface deformities and presence of oxide layers on the surface as compared to the casted samples, which proves it to be having better surface characteristics than casted samples.

V. MICROHARDNESS TEST RESULTS

Table 1 Microhardness of base metal and WAAM metal

AISI-347 BASE METAL (HV)	AISI-347 WAAM (HV)
336.2	344.1
336.2	344.1
335.4	345.4
335.4	345.4

The Vickers hardness test was conducted to know the hardness of the samples which almost tells us which sample will undergo more wear and which sample will undergo less wear. Table 1 shows the micro hardness of both the samples in (HV). The test was conducted at four indentations.

The average Vickers numbers for both the samples are 335.8 and 344.77, which clearly tells us that WAAM samples are much harder than casted samples. As we know that hardness and wear are inversely related higher the wear less hard the material. Hence with this we can conclude that WAAM samples might show less wear compared to casted samples as they have higher hardness number

Wear Test Results (Pin on Disc Apparatus)

Wear test was conducted at global academy of technology on WAAM and casted samples with 10N and 20N loads. To get time vs CoF, time vs frictional force and time vs wear.

Table 2 Initial and Final weight of the sample in grams

Initial weight in grams	Final weight in grams
17.846 (10 N WAAM)	17.842
17.842 (20 N WAAM)	17.837
21.350 (10 N base)	21.345
21.345 20 N (base)	21.135

Table 2 above shows the initial and final weight of the samples, before and after wear conducting wear test at 10 N and 20 N loads. The difference between the weight will be used to get wear rate.

VI. CONCLUSION

Additive manufacturing technology is a new profound technology producing complex components with ease and with a smaller number of defects. Wear is one among these which affects the components performance during its applications hence wear behaviour analysis is one of the important tests which will prove that AM is better than other conventional manufacturing techniques. This project involves in finding wear behaviour and wear rates using pin on disc apparatus which will also help us in finding CoF and frictional force. The samples were manufacture using WAAM and then material characterization was done and later wear test was done both on casted samples and then WAAM samples to understand wear performance.

The following were arrived at:

- Microhardness tests revealed that WAAM samples have higher hardness number compared to casted samples which will tell us that WAAM will undergo less wear.
- The wear tests revealed that WAAM samples have less coefficient of friction compared to casted samples at both the load conditions, which tells WAAM will perform better at high friction conditions.
- The wear tests also revealed that WAAM samples have less wear rate compared to casted sample which indicates its resistance behaviour to wear.
- Overall, WAAM samples have better wear and friction resistance compared to casted samples.

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