Impact of Repetitive Corrugation and Straightening on Microstructure, Mechanical and Wear Properties of Duplex Stainless Steel

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IMPACT OF REPETITIVE CORRUGATION AND STRAIGHTENING ON MICROSTRUCTURE, MECHANICAL AND WEAR PROPERTIES OF DUPLEX STAINLESS STEEL

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Abstract - The experiment's goal is to see how repeated corrugation and straightening affect the microstructure and mechanical properties of duplex stainless steel. After N passes, the ultra-fine grain structure can be obtained using the repetitive corrugation and straightening (RCS) method. During RCS, strain homogeneity has a significant impact on microstructural and mechanical properties. Strain inhomogeneity is caused by a variety of factors, such as die profile and pressing velocity. The working temperature also effect the strain inhomogeneity. The objective material for this study is duplex stainless steel, which will be processed by repeated corrugation and straightening. Furthermore, various conditions can be studied to see how microstructure affects mechanical. Severe plastic deformation (SPD) is a catch-all term for a class of metal working techniques that involve strains extremely large, usually in the presence of a higher shear or complex stress state, as a result of which the defect density is high and the ultrafine grain is equiaxed. RCS (repetitive corrugation and straightening) is a processing technique of sheet metal that involves extreme plastic deformation. A layer is pressed between two dies for corrugation and then between two flattening dies. RCS process is been well-known for producing fine-grained sheet metals. The Vickers testing machine was used for hardness testing, the Universal testing machine for tensile testing, the pin on disc tester for wear testing, and the optical microscope for microstructure characterization. The hardness test and traction test showed that the hardness value and traction strength are increased following the RCS procedure. Due to repetitive bending and flattening of Duplex stainless steel, the grain size has decreased with the increase in the number of grains.

Keywords-Repetitive Corrugation and Straightening, Severe Plastic Deformation, Duplex Stainless Steel, DSS Properties.

1. INTRODUCTION

The stainless steel is a category of iron-based alloys with a minimum chromium content of 11 percent, a composition which prevents iron from rusting and provides heat resistance. Stainless steel contains carbon (from 0.03 percent to more than 1.00 percent), nickel, nitrogen, titanium, copper, silicon, aluminium, niobium, sulphur, selenium, and molybdenum. A three-digit number, such as 304 stainless steels, is sometimes used to identify stainless steel. Duplex stainless steels belong to the duplex family and are a type of stainless steel. Their metalwork consists of approximately equal amounts of austenite (face-centered cubic lattice) and ferrite and is known to be duplex (or austenitic-ferritic) grades (body-centered cubic lattice). Duplex stainless steel is a work hardenable alloy that is highly corrosion resistant. A mixture of austenite and ferrite phases make up their microstructures. As a consequence, properties of both austenitic and ferritic stainless steels can be found in duplex stainless steels. The literature survey about the repetitive corrugation and straightening process and duplex stainless steel material are as follows.

Jenix Rino John Xavier Raj et al.,[1] worked on Ai-Li AA8090 alloy which was processed with repetitive corrugation straightening for ultrafine grain by thermal stability. While the RCS process was carried, the development of S1 (A12CuMg) and T1 (A12CuMg) phases which caused weak softening of this alloy up to 200 ^{0}C. It was observed, based on TOPSIS and the ANOVA results, that temperature (63.03%) had a larger effect on grain coarsening and thermal material degradation than annealing time. A temperature higher than recrystallization temperatures and long annealing period have affected significantly the thermal stability of the RCS processing alloy AA8090. As temperature and annealing time increases, the hardness decreases, and the grain size increases.

Jianyu Huang et al.,[2] studied the capacity for building bulk nanostructured materials of a continuous RCS machine was examined. They noted that after 18 RCS cycles nanostructures had formed. Fatigue broken down on work surface, however, limiting number of cycles of the RCS which could be performed without failure. With the present RCS design the plastic strain is not sufficient to sufficiently refine the grains each cycle. An improved RCS design with considerable shear strain on the workpiece has successfully shown grain refinement capabilities and requires additional research.

Wei Gong et al.,[3] investigated the effects of Ce on the microstructure and mechanical properties of LDX2101 duplex stainless steel. The key inclusions in steel are irregular and large scale Al2O3 and Al2O3-MnS when the Ce content is zero percent. CeAlO3, Ce2O2S, and Ce2O3 are the most common spherical and small size inclusions in steel when the Ce content is 0.005 percent or 0.02 percent. Ce will purify molten steel at the same time, reducing the number of inclusions per unit area. Ce will also help to optimise the grain structure of LDX2101 duplex stainless steel and reduce the average grain size. The mechanical properties of LDX2101 duplex stainless steel can be improved with Ce. Grain refinement strengthening and solid solution strengthening improve the steels' tensile and yield strength by 4.69 percent and 2.83 percent, respectively. At the same time, grain refinement strengthening increases the plasticity of the steels by 4.9 percent, thus reducing the size and quantity of inclusions, adjusting inclusions, and refining grains increases the effect hardness of the steels by 14.5 percent.

Prabhakar M. Bhovi et al.,[4] The impacts of two SPD procedures, namely RCS which is repeated torsion and straightening and HPT that is high-pressure torsion, have been examined. They experimented with the Al-3Mg-0.25Sc alloy. In its initial state, the alloy had a grain size of 150m and a hardness of Hv 50. The findings revealed that eight-pass RCS processing resulted in considerable cereal refining, average grain sizes of 0.7m and hardness of Hv 110. HPT-TM treatment for one spin at room temperature at 6.0 gpa pressure resulted in a reasonably uniform microstructure with an average size of €95nm with an average Hv ~150-156 hardness. The results have shown that HPT processing generates smaller grain sizes, greater microhardness values for Vickers and a more homogenous microstructure than RCS.

Nozomu Adachia et al.,[5] studied the mechanical characteristics of high-pressure torsion process ultra-fine grains of pure Fe were explored. The combination of high pressurised torsion and glueing procedures was used to produce ultrafine, pure Fe grain samples of varied grain sizes. After the link between Hall and Petch, the tension of the samples rose by 0.2% as grain size fell. The As-HPT sample shows a more even elongation in comparison to other samples with a tiny grain size of 0.320 m. The As-HPT sample with a very consistent elongation accommodates strained evenly irrespective of the grain orientation, using an in-situ neutron diffraction experiment to evaluate the variability of the lattice strain in different lattice planes.

2. MATERIALS AND METHODOLOGY

2.1 Material Selected

Duplex stainless steel grade 2205 is the material used for this experiment. 2205 Duplex stainless steel is a two-stage austenitic and ferritic alloy with 22% chromium, 5% nickel and 3% molybdenum alloy steel. It is the most often used grade of duplex which has double the output strength of conventional stainless steel of austenitic grade. It is also resistant to stress corrosion, crevice, pitting, erosion and general corrosion in harsh conditions, and has a strong fatigue strength.

Table 1: Chemical composition Duplex stainless steel 2205

Grade	C	Si	Mn	S	P	Cr	Mo	Ni
2205	0.03 max	1.0 max	2.0 max	0.03 max	0.02 max	min: 21.0 max: 23.0	min: 2.5 max:3.5	min:4.5 max: 6.5

Table 2: Duplex stainless steel's Mechanical properties

Sl No.	Grade	2205	UR52N+
1.	Tensile Strength (MPa)	620	770
2.	Proof Stress 0.2% (MPa)	450	550
3.	Elongation A5 (MPa)	25	25

Table 3: Duplex stainless steel's Physical properties

Sl. No.	Property	2205	UR52N+
1.	Density (g.cm^3)	7.805	7.810
2.	Modulus of Elasticity (GPa)	200	205
3.	Electrical Resistivity (Ω.m)	0.85×10^-6	0.85×10^-6
4.	Thermal Conductivity (W/m.K)	19 to 100° C	17 to 100° C
5.	Thermal Expansion (m/m.K)	13.7*10^-6 to 100° C	13.5×10^-6 to 200° C

2.2 Properties of Duplex stainless steel

Strength: Stainless steel of duplex grade is about twice the strength of normal ferritic or austenitic grade.
Corrosion resistance: The resistance to corrosion depends, like all stainless steels, mainly on the stainless-steel composition. Duplex grades of stainless steel have a range of resistance to corrosion similar to the range of austenitic stainless steels.
Heat Resistance: Duplex stainless steel, which is high in chromium and protects against corrosion, causes fragility in temperatures above 300°C. Duplex steels have better ductility than ferritic and martensitic grades at low temperatures. It is readily possible to use Duplex grades down to -50°C or less.
Toughness and ductility: Duplex stainless steels are much tougher and more ductile than the ferritic grades, but they do not attain the excellent austenitic grade values.
Stress corrosion cracking resistance: Duplex stainless steels display a strong resistance to stress corrosion (SCC), which is an inherited property on the ferritic side.
Heat Treatment: Unable to heat treatment, stainless steel duplex is not hardened. However, they can be hard worked. After heating to about 1100°C, quick cooling or cleaning can be done.
Fabrication: Only tools dedicated to stainless steel material should be used to manufacture all stainless steel. Before use, surfaces for tools and work shall be thoroughly cleaned. These precautions are necessary to ensure that the surface of the fabricated product is not cross contaminated by stainless steel by easily corroded metals.
Cost: Stainless steel of duplex grade has a lower content of molybdenum or nickel than its austenitic grade with resistance similar to corrosion. Dual alloy stainless steels can be less expensive, especially in high alloy surcharges due to their lower alloy content.

2.3 Methodology

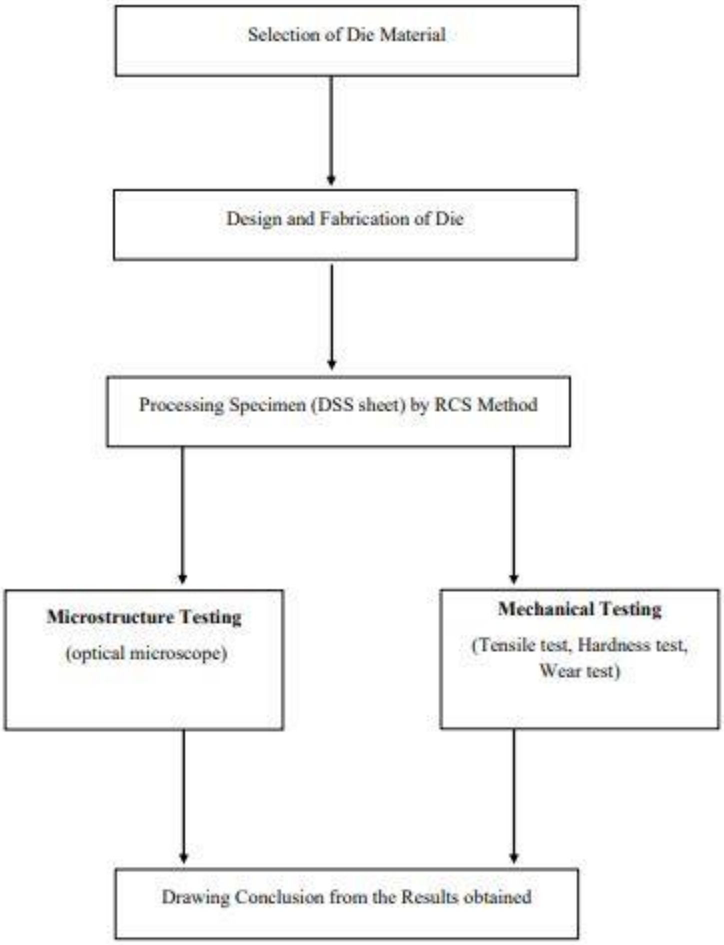


Figure 2.1: Flow Chart of Experimental Work

2.4 **Material Processing**

The process of Repetitive Corrugation and Straightening includes the uses of dies. This method is commonly used because it is an easy and inexpensive way to increase the number of grains while also reducing grain sizes. The properties of the materials are taken into consideration when selecting materials. The properties of the die material must be superior to those of the test material. The substance under consideration is sandwiched between the dyes. The UTM's load is used to bend the sheet of the material that is being taken. The bending and flattening of the material in use are also part of this method. There are a number of other parameters and instruments that are used in this operation.

2.5 Die Design

The Hot Dye Steel is the material that we are considering for the die. H13, also known as hot die steel, is a hardening tool steel that has excellent hardness and toughness and can be used in a wide range of applications. We looked at four different dye blocks. - one is 150mm*90mm*40mm in size. Two of the dyes are grooved, while the other two are defined as smooth. The grooved dye has a semi-circular dye that measures 6mm in diameter. This allows us to bend the material with the grooved dye and flatten it for several passes with the flat dye. The dye was machined using both a grinding machine and a milling machine.

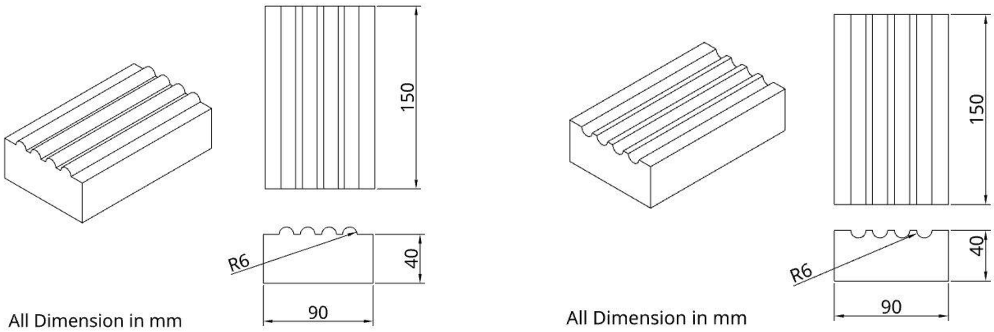


Figure 2.1: CAD design of Die

The mechanism that we are going through is depicted in figure. We'll start with the semi-circular grooved die. The DSS layer is then placed between the two dyes and the incremental load is applied using a universal testing machine. The deformation of the DSS sheet occurs, resulting in changes in the gain sizes and grain number. The sheet is then flattened by repeating the process but replacing the semi-circular dye with flat dye. After that, we go through a series of cycles before we reach saturation.

The grinding machine is depicted in figure. Grinding is a type of surface finishing that involves removing a very thin layer of material in the form of fine dust particles. (thickness ranges from 0.25 to 0.5mm). Grinding is a material removal procedure that uses an abrasive motion between a spinning abrasive wheel and the work piece to remove material. A grinding machine is a power-driven machine tool that removes a thin layer of material from a work piece by feeding it against a continuously spinning abrasive disc, also known as a grinding wheel.

3 EXPERIMENTS

3.1 Hardness Test

The hardness test was performed using the Microhardness Tester / Hardness Tester Vickers. ASTM E-384 Micro hardness tests are used to produce indentations measured and converted in hardness by a diamond indenter, covering a range of low stresses. It is beneficial for evaluating a wide range of materials, but it is important to polish test samples extremely well to measure the size of the imprints. The Vickers scale uses a square base diamond and a pyramid form for testing. Charges are usually in the range of 10gm to 1kgf although "Macro" loads of Vickers can weigh as much as 30 kg or more.

3.2 Tensile Test

Tensile tests were performed using the UTM. Tensile tests are one of mechanical testing's most basic and commonly utilised kinds. Tensile tests include the application of the tensile force on a material and measurement of the reaction of the specimen to stress. Tensile tests show how powerful a material is and how far it can be stretched.

3.3 Wear Test

Wear is the gradual decrease in relative movement of material from the solid surface. Wear is the name of the material distortion or progressive loss from solid surfaces. The test of wear was carried out by means of a pin on a disc wear tester, load 10, 20 and 30N were given to the test.

3.4 Microstructure Test

Duplex stainless steel microstructural characterization with optical microscope. The samples have been produced according to normal methods and the results have been photographed using optical microscope.

4. DISCUSSIONS AND RESULTS

4.1 Hardness test results

4.1.1 Hardness test of Duplex stainless steel before RCS process

Table 4.1: Hardness test values before RCS process of DSS

Point	Distance	Hardness	Diagonal X	Diagonal Y
1.	0,100mm	143.3 HV	0.114mm	0.113mm
2.	0.200mm	147.9 HV	0.111mm	0.113mm
3.	0.300mm	152.6 HV	0.108mm	0.113mm
4.	0.400mm	147.1 HV	0.107mm	0.118mm
5.	0.500mm	153.0 HV	0.107mm	0.114mm

Table 4.2: Mean hardness results

Mean	Minimum	Maximum	Range	Std. deviation
148.8	143.3	153.0	9.7	4.1

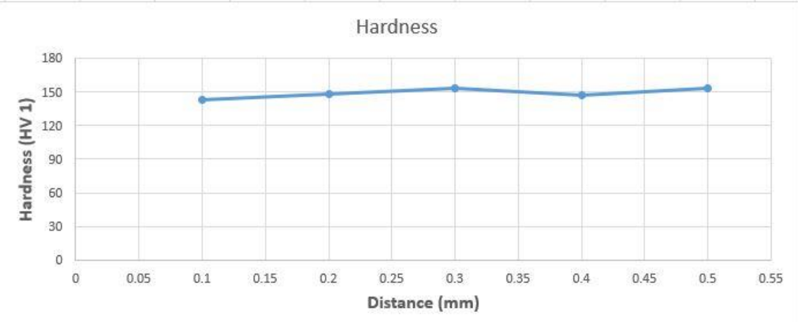


Figure 4.1: Hardness test values graph before RCS process

4.1.2 Hardness test results of Duplex stainless steel After RCS process

Table 4.3: Hardness test values after RCS process of DSS

Point	Distance	Hardness	Diagonal X	Diagonal Y
1.	0,100mm	181.8 HV	0.121mm	0.124mm
2.	0.200mm	179.5 HV	0.119mm	0.124mm
3.	0.300mm	183.7 HV	0.077mm	0.0.86mm
4.	0.400mm	188.2 HV	0.122mm	0.127mm
5.	0.500mm	185.1 HV	0.119mm	0.127mm

Table 4.4: Mean hardness results

Mean	Minimum	Maximum	Range	Std. deviation
183.6	179.5	188.2	8.7	3.29

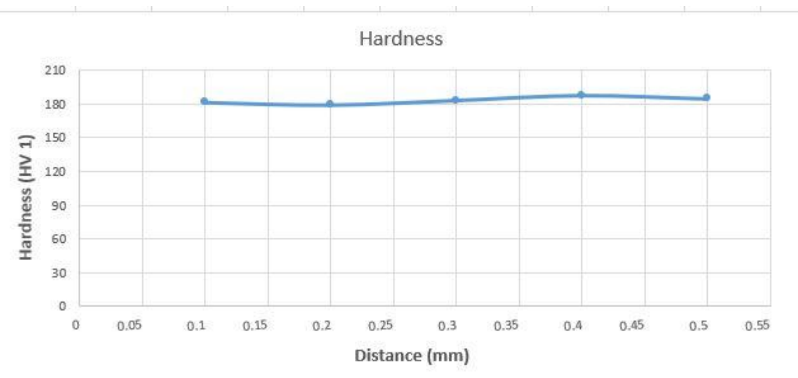


Figure 4.2: Hardness test values graph after RCS process

Above the results of hardness test of duplex stainless steel before and after RCS process. Figure 5.1 shows hardness test values graph before RCS process and Figure 5.2 shows hardness test values after RCS process. Five indentations took place at five sites for each. The mean hardness before RCS process in 148.8 HV whereas the mean hardness after RCS process is 183.6 HV. The hardness of duplex stainless steel has been increased by 34.8 HV which is by 23.4% after RCS process.

4.2 Tensile test results

4.2.1 Tensile test results of Duplex stainless steel before RCS process

Table 5.5: Tensile test value before RCS process of DSS

Peak stress	156.887 MPa
Peak Load	4.707 kN
Limit of Proportionality	49.021 MPa
Elongation at Break	5.2 %
Yield Stress	92.004 MPa
Yield Strain	0.616 %
Yield Load	2.76 kN
Yield Point Extension	0.247 mm
Strain Hardness Coefficient	321.88 MPa
Stiffness	15.798 kN/mm

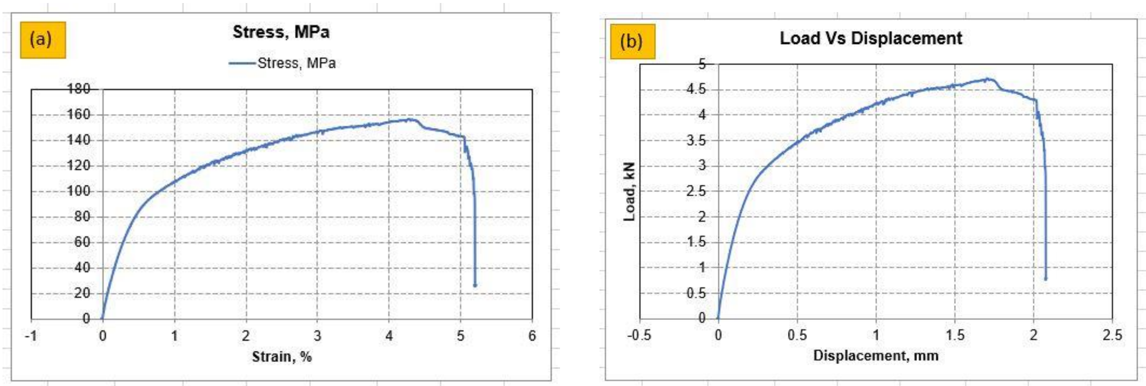


Figure 4.3: Tensile test value of duplex stainless steel before RCS process, where (a) is Stress vs Strain, (b) Load vs Displacement

4.2.2 Tensile test results of Duplex stainless steel after RCS process

Table 4.6: Tensile test value after RCS process of DSS

Peak stress	177.916 MPa
Peak Load	5.337 kN
Limit of Proportionality	62.211 MPa
Elongation at Break	6.15 %
Yield Stress	93.29 MPa
Yield Strain	0.643%
Yield Load	2.799 kN
Yield Point Extension	0.257 mm
Strain Hardness Coefficient	373.209 MPa
Stiffness	14.995 kN/mm

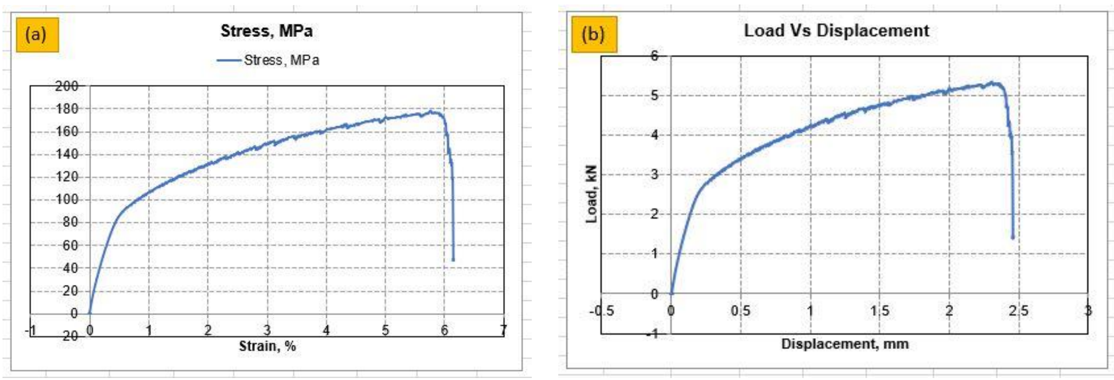
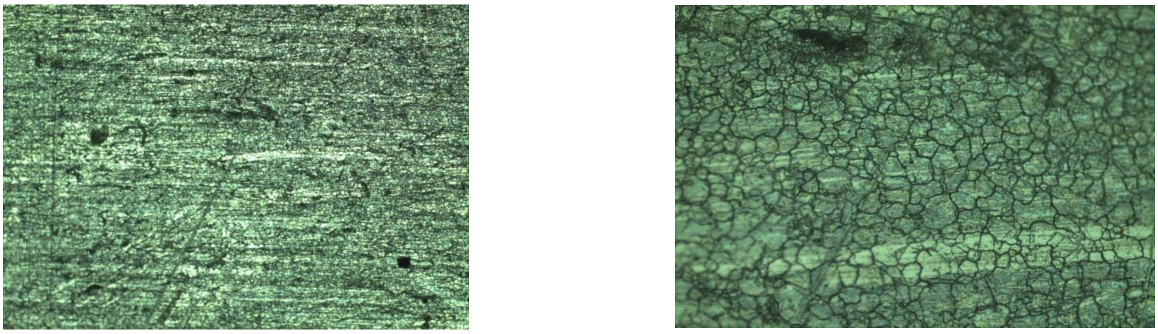


Figure 4.4: Tensile test value of duplex stainless steel after RCS process, where (a) is Stress vs Strain, (b) Load vs Displacement

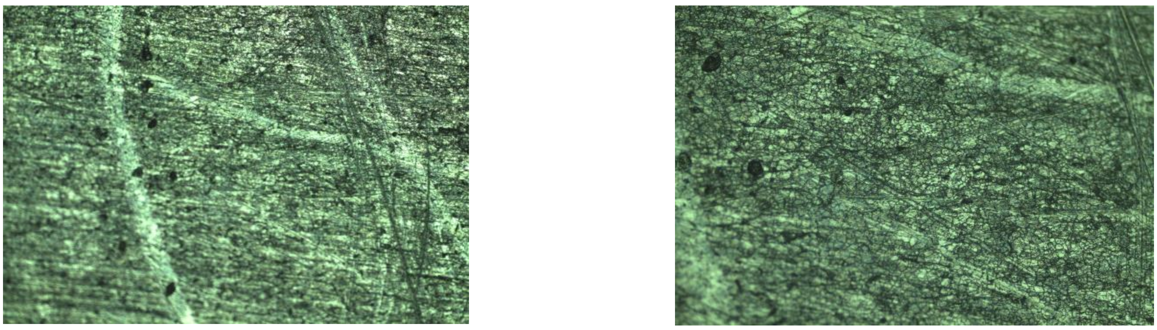
Figure 4.4 depicts the curve of the stress of duplex steel. The gauge length and width of the given specimen is 100mm and 20mm respectively. The thickness of the material is 0.8mm. The peak stress before RCS process was 156.887 MPa, while the peak stress after RCS process is 177.916 MPa. The peak load applied for material before RCS process is 4.707 kN and the peak load applied after RCS process is 5.337 kN

4.3 Microstructure Characterization



(a) 100x (b) 500x

Figure 4.5: Microstructure Characterization of duplex stainless steel before repetitive corrugation and straightening where (a) at 100x and (b) at 500x



(a) 100x (b) 500x

Figure 4.6: Microstructure Characterization of duplex stainless steel after repetitive corrugation and straightening where (a) at 100x and (b) at 500x

Figure 4.5 shows optical micrographs of duplex stainless steel before repetitive corrugation and straightening process and Figure 4.6 shows after process which shows fine grains in the microstructure. It is observed the flattened and elongated grains due to repetitive corrugation and straightening process. The lighter part of the picture is austenite seed, while the darker part is the ferritic matrix.

4.4 Wear test results

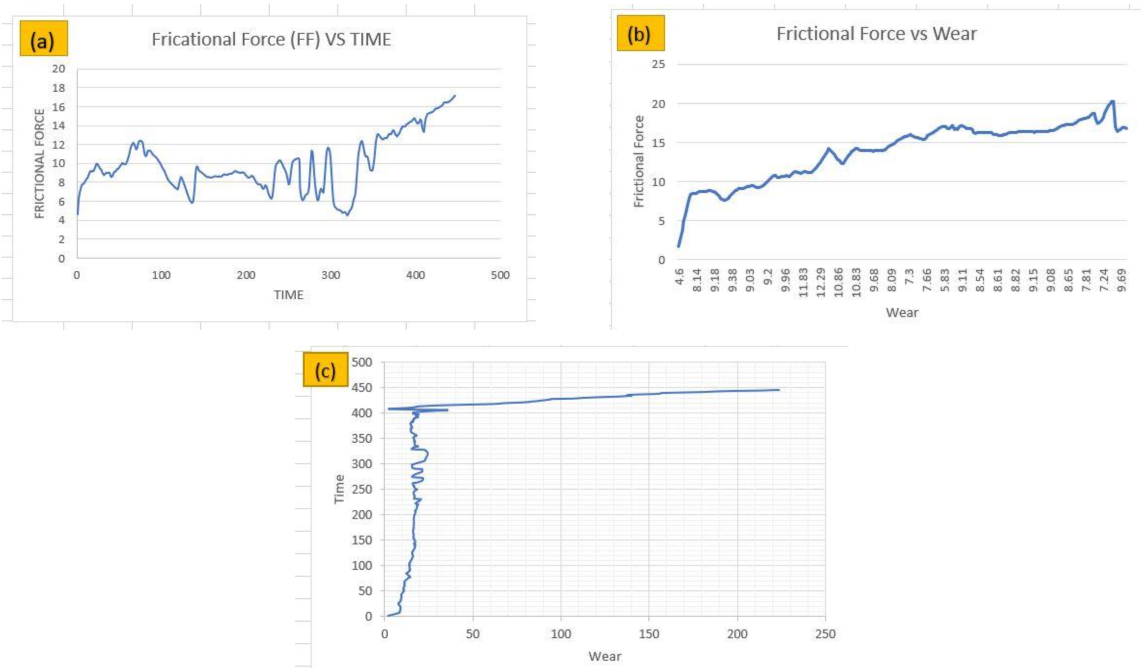


Figure 4.7: Wear test value of duplex stainless steel, where graph (a) Frictional force Vs Time, (b) Frictional Force Vs Wear, (c) Time Vs Wear

Figure 4.7 shows the results of wear test of duplex stainless steel using pin on disc wear tester. The wear rate increases with the increase of load. The coefficient of wear is calculated using V*H/F*S, where volume of material is V, H is hardness of material, F is the frictional force acting on the material. The calculated wear coefficient of duplex stainless steel is 0.017x10

5. CONCLUSIONS

After the process we see that there are a number of changes that is being taking place in the material. We conduct this process for a number of passes till we reach a saturation point till no much variation is seen in the properties. The tensile property of the material increases with the number a pass. Ductile nature of the material is seen to increase. The hardness value of the material also increases. While this process is being carried out, we notice that due to repetitive bending and flattening of the Duplex Stainless Steel the gran size decreases with the increase in the number of grains

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