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Breakage Analysis of Aluminum wire rod in Drawing Operation

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Abstract - *Commercial aluminium rod and wire for electrical cable manufacturing involves different operations, such as a long square ingot is heated, progressively reduced in cross-section by passing it through a series of rolls and then coiled. The coils are then pulled through smaller and smaller dies in wire drawing operation to obtain the required wire size.*

Because of the high tool and equipment investment involved, it is vital to understand the relationship between the condition of the equipments and their performance measured in terms of productivity and recovery. This is in turn necessitates an understanding of the contribution and controlling factors related to product defects in rolling and subsequent breakage in wire drawing operation. The production breakdown leads to resetting of the workstations resulting in wastage of time and production loss.

The quality of drawn wire and breakage during drawing operation is a function of various factors, such as die pass schedule and die details, wire rod properties, machine parameters like cooling and lubrication of dies and drum etc. An attempt is made by the investigator to trace their mechanical and metallurgical causes and to suggest viable corrective/preventive measures. Finite element method is used to analyze the process parameters in the wire drawing process.

Keywords: Cold forming, rolling, wires drawing, defects origin, flow patterns, FEA model analysis

1. INTRODUCTION

A cable is two or more wires running side by side and bonded, twisted, or braided together to form a single assembly. Electrical cable is an assembly consisting of one or more conductors. Aluminium and its alloy conductors are preferred and dominant for cable in several areas of power transmission and distribution. The major areas dominant by aluminium and its alloys cables are non-insulated overhead power transmission, insulated overhead power transmission and distribution. It is because of its strength to weight ratio and cost with respect to copper, though its conductivity is about 60% of that of copper.

1.2 Cable manufacturing process

Manufacturing of different overhead transmission cables involves a broad range of complexity depending on the cable design to be produced. A cable goes through several manufacturing stages before exiting in the factory and gets delivered to the clients.

Commercial manufacturing of aluminium cable starts with melting the billets in furnace and alloying if required. Then liquid aluminium is taken into a stilling furnace to provide stability of flow and casting continuously. After this stage liquid aluminium is cooled on casting wheel and aluminium bar is forced into rolling machine to shape 7.6mm, 9.50 mm or 12mm wire rod. The wire rod so produced is packaged in 1-2 tons on tight coiled pallets for further operation. Quality controls like checking the diameter, resistivity, strength and shape of rod and chemical composition are to be carried out to meet international standards.

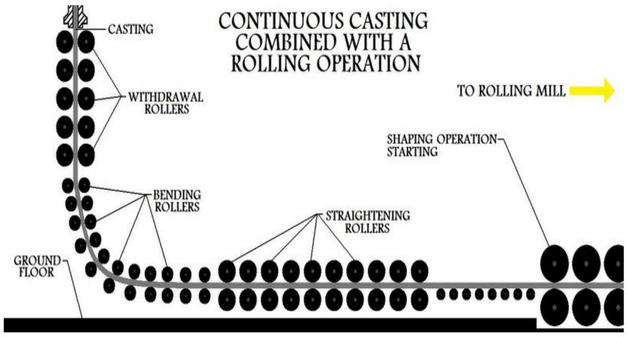


Fig. 1: Continuous casting process [1]

1.3 Defects in Wire

Wire rod during the drawing operation is a plastic deformation process under drawing force, pressure and friction condition. If the drawing equipment had poor lubrication, shortage of cooling or die eccentric, wire drawing would be caused to fracture. Fracture and surface morphology were very important to failure analysis of wire drawing fracture. Generally, fracture modes were corresponded to macro fracture morphology and surface state of wire.

Wire drawing is characterized by a continual generation of new surface. As more and more new surface is generated the lubricant film becomes thinner. If the lubricant film is reduced below the boundary lubrication limit, then surface damage is unavoidable. Following are some of the surface defects [4].

1.3.1 Surface Scrap

A surface scrap or fins as shown in fig.2 are loosening of surface material only partly connected to the wire surface. Detachment appears along the wire axis. A possible origin of this structure is a lateral defect prior to drawing process, defect which is drawn over in the following working steps, leading to material detaching from the surface.

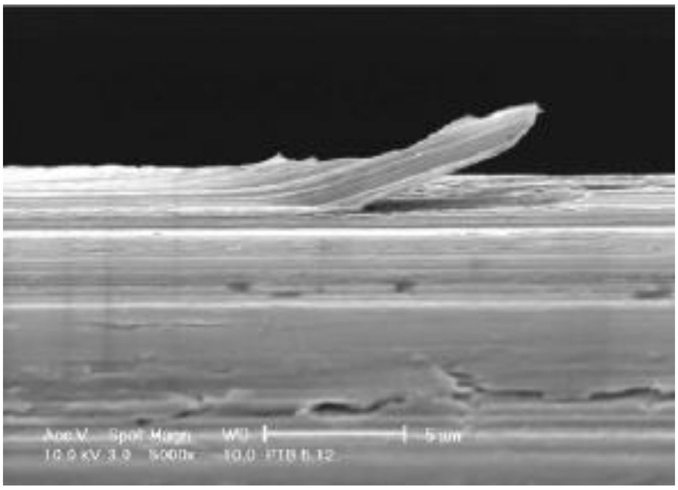


Fig. 2: Surface Scrap

1.3.2 Surface Spills

Spills as shown in fig.3 are loosening of surface material only partly connected to the wire surface. Detachment appears perpendicular to the wire axis. They may be generated by a wire rod defect during hot transformation, over rolling of material.

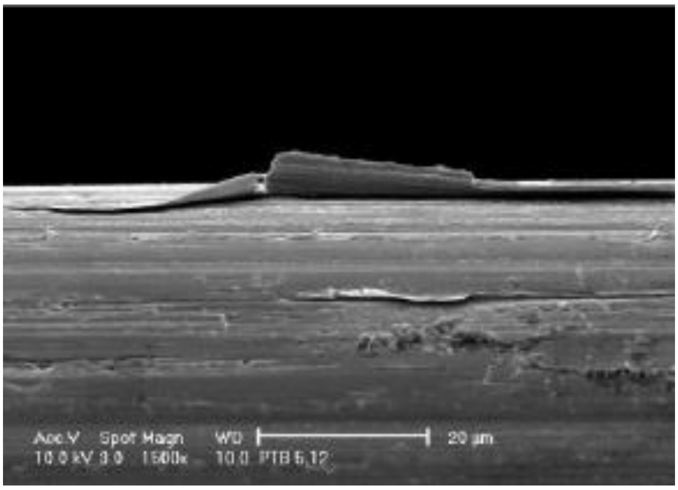


Fig. 3: Surface Spills

1.3.3 Surface Inclusions

An inclusion is a material pressed into the wire surface as shown in fig.4. Its origin is the drawn-in or pressed-in material, originating, e.g. from tool fragments during processing, from incorporation of material into the wire rod surface or from metallurgical incorporation close below the wire rod surface, which appear on the surface during subsequent steps of processing or corrosion of the original material, if it is not resistant to corrosion.

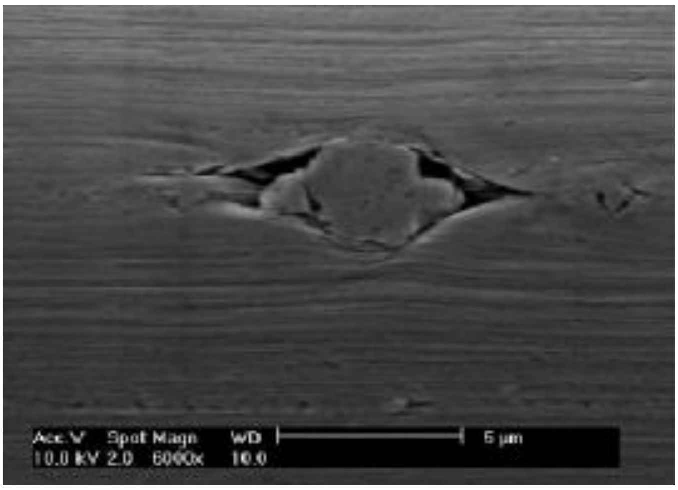


Fig. 4: Surface Inclusion

1.3.4 Surface Pores

As shown in fig. 5 pores are multiply occurring small deepening in the wire surface due to improper pre-processing of the wire rod. Pores may appear due to over etching or corrosion of the material, if it is not resistant to corrosion.

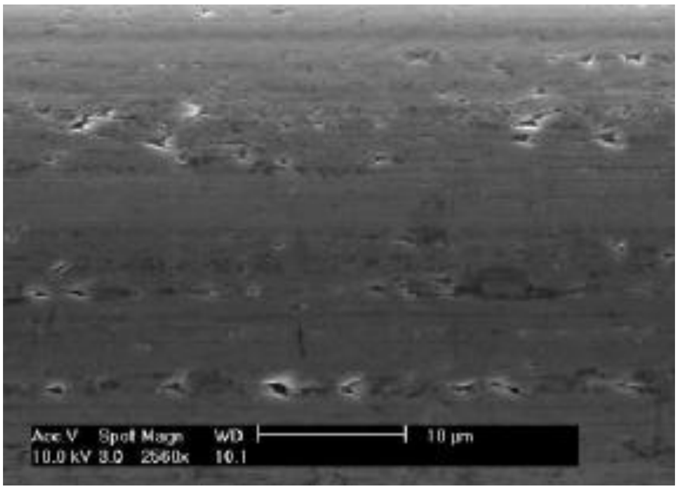


Fig. 5: Surface Pores

1.3.5 Surface Protuberances

Protuberances are linear protrusions of limited length on the wire surface parallel to its axis as shown in fig.6. A possible origin for this structure is that the die inner surface is too rough.

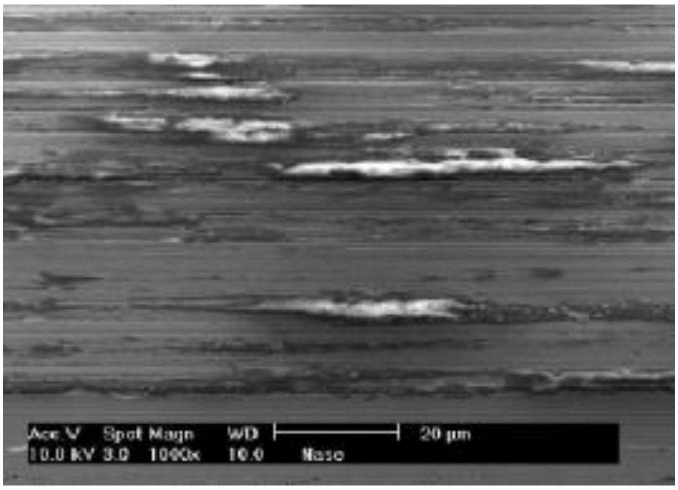


Fig. 6: Surface Protuberance

2. LITERATURE REVIEW

3-D finite element analysis for single pass and multi-pass wire drawing in order to evaluate the deformation behavior of various surface defects having different aspect ratio. They found that the numerical simulations results match well with experimental results for introduced of any arbitarily longitudinal, transverse, oblique and round defects possibly formed during both of the wire drawing process [2]. Metallographic observation on polished samples gives key information on surface defect origin on carbon steel bar and wire using several reagents. They also observed pin holes on billet due to sand blasting, on rolling may disappear due to scale formation for small holes and get elongated in rolling direction for larger holes. They found that transverse cracks in billet, during rolling with high reduction ratios creating longitudinal defects [3]. Industrial experiments in a steel company and suggested that the removal of defects is either performed selectively by removing the specific defect on the surface specific to the semi-finished products continuously cast. They suggested discovering the generating source of inclusions during casting and rolling operations to take the proper measures and take remedy where appropriate for preventing failure in subsequent drawing operation [4].
The temperature of H-beam was a downward trend in the hot rolling process, however, local temperature display rising trend, uneven deformation of flange lead to more complex temperature distribution, there is certain correlation between equivalent plastic stress and temperature distributions, increasing of equivalent plastic stress as the temperature increases, research results can provide theoretical basis for rolling regulations and reference of the production of hot rolling for H-beam [5-8]. A series of different metallic materials, diameters and production environment by scanning electron microscopy and conical microscopy analyzed. With the image of the structure for the surface quality of the metallic wire, a nomenclature and cause for each surface defect is proposed. The catalogue of surface defects creates a basis for developing instruments for measuring surface quality of wire for checking the breakage of wire in subsequent drawing operation [9]. The effect of several geometry parameters on the wire drawing process using a 5052 aluminium alloy considering strain hardening damage studied. They obtained that, within the study interval, the most significant effect on the plastic deformation is the section reduction, followed by the semi-cone angle of the die and the friction coefficient although this to a lesser degree. They also found a high value of plastic deformation in the material can lead to an excessive level of damage inside the wire. The accumulated damage mainly depends on the semi-cone angle of the die and to a lesser extent, on the percentage of section reduction, being the effect of the friction coefficient very low [10]. The analytically and numerically the parameters affecting wire drawing process using a 3D finite element model DEFORM-3D V6.1 and material aluminium-1100 for simulation investigated. They found that the increasing in bearing length causes an increase in the drawing force and to avoid the increase drawing force, the reduction in area and friction coefficient should be small with a large die angle. They also observed that with certain range of velocities, drawing force decreases with increase in velocity and failure takes place when the velocity goes out of this range [11]. The influence of the microstructure on the physico-mechanical properties of Al-Mg-Si alloy. The alloy was nano-structured using sever plastic deformation by high pressure torsion at different deformation range investigated. They found ultrafine grain structure with nano-inclusions of secondary phases and an excellent combination of high strength and electrical conductivity [12].

Metallurgical investigation of different causes of center bursting led to wire breakage during production carried out. They found with experimental observations that grain flow, porosity and internal cracks etc in material leading to metallurgical defects in raw material and cause material failure. They also observed the presence of hard brittle phase which makes the central fibers brittle and create center bursting in wires. The central bursting formation in wires led to wire breakage [13].

The experimental work to predict the formation of chevron crack in copper wire drawing process, found the chevron crack formation initiated by a central burst inside the wire material using experimental tests. The results when compared with the results from a series of numerical simulations using the Cockcroft–Latham fracture criterion, found in the conditions of central burst formation along the wire axis, depending on drawing parameters and friction coefficient between the die and the wire. The friction coefficient is a linear function of temperature rise which is measured close to the wire die interface [14]. The formation of edge defects in hot strips, resulting from slab corner cracks generated in continuous casting. They developed a model-based concepts for the identification of such initial slab cracks. To accomplish this task a systematic finite element tool Deform-3D was utilized. The numerical results clearly pointed out the significant morphological changes of the cracks during rolling and afford valuable indications for a deeper understanding of the underlying process details [15-17]. The old drawing device had the problems of low stiffness of the guiding die and of short service time of peeling die with poor roughness of peeled wire surface. They proposed a multi-step process which includes front guiding, drawing, peeling, redrawing and rear guiding. Based on the principle of metal cutting and researched results, it was found, the peeling-redrawing die that had a long durability and improved the wire surface quality after peeled and redrawn [18]. The size and length effects of an inclusion on multi-pass copper wire drawing with optimal die half-angle by two-dimensional finite element analysis investigated. They observed necking on the wire containing an inclusion and maximum hydrostatic tensile stress occurred on wire centerline in front of inclusion for single-pass drawing. When the wire was repeatedly drawn, the maximum hydrostatic tensile stress regions symmetrically separated out and were at both side of wire centerline in front of inclusion [19]. The influence of casting parameters on casting conditions and interference of casting parameters on the final strip characteristics such as constant strip thickness, surface quality and roughness of aluminum alloys sheet 6.30 to 6.50 mm thick. They also found that casting speed, roll force and roll gap should have the greatest influence on the final strip thickness and the examined parameters agree well with the theoretical values [20]. J-integral value increased with the increasing of the angle of drawing die, the friction coefficient between drawing die and wire and the initial dimension of the flaw. When friction coefficient equaled 0.1, J-integral value round the crack tip with the same flaw decreased with the decreasing of the angle of the die. J-integral value changed slightly and tended to be a constant value when the angle reached to 8°. They found that maintaining low friction and best pull out angle of dies, rate of breakage of wire can be reduce in production process [21]. Deformation characteristic of low carbon steel under hot compression conditions at the temperature range of 650–1000^{0}C using Gleeble 3800 thermo-mechanical simulator for the formation of micro-cracking observed. They found the change of microstructures using an optical microscope. The hot deformation process was numerically simulated using finite element technique to determine the local strain, strain rate, and temperature distributions. They also observed the microstructure changed quite differently after the deformation at various temperature levels. The grain size and shape were also varied during the deformation process depending on the characteristics of metal flow. The initiation of micro-crack was found to be strain and temperature dependent. Such a micro-cracking was easy to initiate at the position with high stress and strain, especially at the grain sliding boundaries [22]. They developed illumination system with blue LED lighting sources to get best quality of surface image and implemented defect detection algorithms based on block sigma transform which can recognize wire rod objects and segments defect from the images in robust and efficient manner [23]. Drawing operation using ANSYS found that provision of die land and fillet at die entry made the material flow smooth, less stress and low heat generation analyzed. Hence least wire defect drawing defects and wire breakage [24].

The role of residual stresses on wire fracture strength in drawing operation using 5052 aluminium alloy observed. They found that maximum value of axial stress increases when the semi-cone angle of the die increases or cross section area reduction decreases. They also found that compressive residual stresses reduce crack growth but tensile residual stresses on the surface of the wire causes more damage [25]. The wire drawing process of polycrystalline diamond (PCD) wire drawing die using ABAQUS FEA software for drawing solar wafer cutting wire and obtained a maximum stress of die blank to find the drawing force studied. The investigators analyze the effect of different reduction angle on drawing force on same PCD die .From the experiment the investigators concluded that for the reduction of drawing force and the equivalent stress of PCD shaper hole, the reduction angles of shaper hole should be set in the range of 7^0- 8^0 [26]. The damage evolution of the drawn wire in each of the eight passes and observed the damage distribution along axial and circular directions. Wire breakage expected to occur in those areas of the drawn wire where fractures most possibly initiate. They found damage evolution on the surface of the wire due to sticking friction [27]. The calculation of lubricant film thickness with drawing parameters and concluded that lubricant film thickness increases when die angle increases. Lubricant not only improves the surface finish of the product but also act as heat insulation between the billet and the die. He also suggested that a lubricant selected for drawing operation will not shear too easily and chance of failure or rupture of wire with high viscosity lubricants [28]. Microstructure evaluation of FSW joints clearly shows the formation of new fine grains and refinement of reinforcement particles in the weld zone with different amount of heat input by controlling the welding parameter [29-30]. The lubricant concentration in the emulsion used in wire drawing control the friction and wearing of contact surfaces. They found that change in emulsion concentration for certain lubricant influences friction parameters as well as wear parameters in the process of wire drawing and control the speed of wire drawing through the matrix [31]. The vibration behavior of wire in wire drawing process was observed .They found that wear profile and generation of ringing on die is due to the effect of wire vibration. It was also observed that simulation Abaqus FEA result and experimental result are same. Thus they concluded that simulation can be used to accurately predict the die wear profile [32]. FEM tool designed to simulate wire drawing can generate practical information for the analysis and optimization of output wire properties concluded. The possibility of central burst can be analyzed by looking at the tri-axially of the stress state on the central line or as accumulated damage [33]. A failure analysis procedure of steel wire drawing using metallographic examination and microscopic analysis and found that fracture modes are corresponded to macro fracture morphology and surface state of wire [34].

3. PROBLEM DESCRIPTION

The aim of this work is to understand the cause of defects leading to breakage during wire drawing operation for aluminum alloy cable. The wire material was Al-Mg-Si alloy of grade 6201.The breakage of wire during drawing operation occurs sometimes in random. Since the breakage of wire during the drawing operation is a random error the breakage samples of wires for input wire rod as well as processing wire of intermediate dies stations are under investigation for their causes and effects. Metallurgical limitation in input wire rod material for porosity, internal cracks and inclusions are to be studied. Metallographic study of wire internal as well as surface quality is to check using scan electron microscopy. Wire tensile failure mode is also verified from flow stress to draw stress ratio taking die geometry and friction condition into consideration. Since random breakage is the subject of study, simulations for different friction condition are carried out for an optimum result.

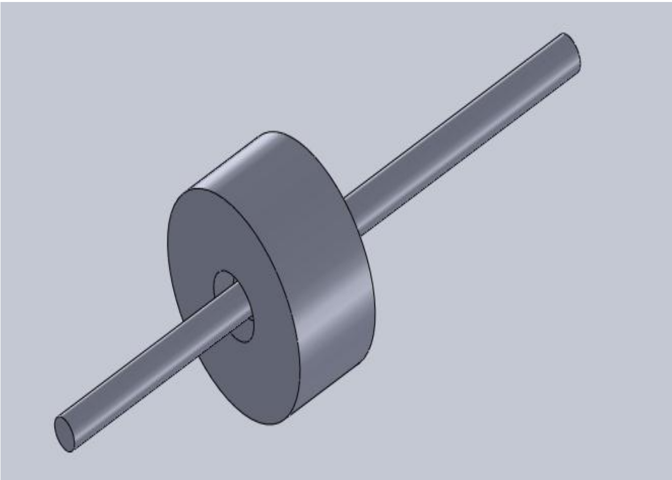


Fig. 7: 3D CAD model for die and wire assembly for die no.5

3.1 Material Properties

Table 1: Material properties for wire rod

Wire material density(ρ)	= 2.74 x 10^{-3} Kg/m^3
Young' s modulus (E)	= 7.03 x 10^{10} N/m^2
Poisson ' s ratio (μ)	= 0.34
Rigidity modulus (G)	= 2.5 x 10^{10} N/m^2
Bulk modulus (K)	= 7.5 x 10^{10} N/m^2
Thermal conductivity (K_t)	= 244 W/mK
Specific Heat (C_p)	= 875 J.Kg^{-1}K^{-1}

Table 2: Material properties for Poly Crystalline Dies:

Die material density (ρ)	= 3.43 gm/cc
Compressive Stress	= 4.74 GPa
Fracture toughness	= 6.89 Mpa/m
Young' s modulus (E)	= 925GPa
Poisson ' s ratio (μ)	= 0.086
Rigidity modulus (G)	= 426GPa
Bulk modulus (K)	= 372GPa
Thermal conductivity (K_t)	= 120 W/m K

4. RESULT AND DISCUSSION

Aluminium wire drawing is a cold working plastic deformation process. The wire passes through a series of dies where compressive stresses act along the two axes and tensile stress along the third axis. The plastic deformation in the metal takes place only when the applied stress level exceeds the yield stress but less than the fracture strength of the metal. Thus for successful wire drawing operation the drawing stress should never exceed the flow stress. If material composition is not uniform and voids or slag inclusion present in the material, then fracture strength is uncertain and it leads to breakage of wire rod in drawing operation.

4.1 Metallurgical Analysis

The plastic deformation in drawing is achieved through dies with uniaxial tension and biaxial compression. Thus grains should elongate in the drawing direction and contract in all directions perpendicular to the wire axis. Plastic deformation takes place due to shear stresses which are produced by normal stresses from tensile and compressive forces. Deformation takes place by slip or twinning phenomena in the metallic crystals. However imperfections in form of point imperfection, line or surface imperfection affects the deformation process. When load is applied to a material, shear stresses build up and entire atomic planes are shifted relative to one another within dislocations and allow deformations. But when many of these dislocations have moved to a grain boundary the stress at these boundaries becomes too great and fracture begins to occur. From metallurgical viewpoint the process of fracture under gone through three steps.

- Plastic deformation to produce dislocation pile-ups
- Crack initiations
- Crack propagations

The initiation of micro cracks are greatly influences by the presence and nature of second phase particles bonded to the matrix. During deformation the dispersion of second phase particles readily cut by dislocations causing planar slip and relatively large dislocation pile ups. This will leads to high stresses, easy initiations of micro-cracks, leads to void formation and ductile fracture.

4.1.1 Analysis of Visual Inspection of Wire Breaks

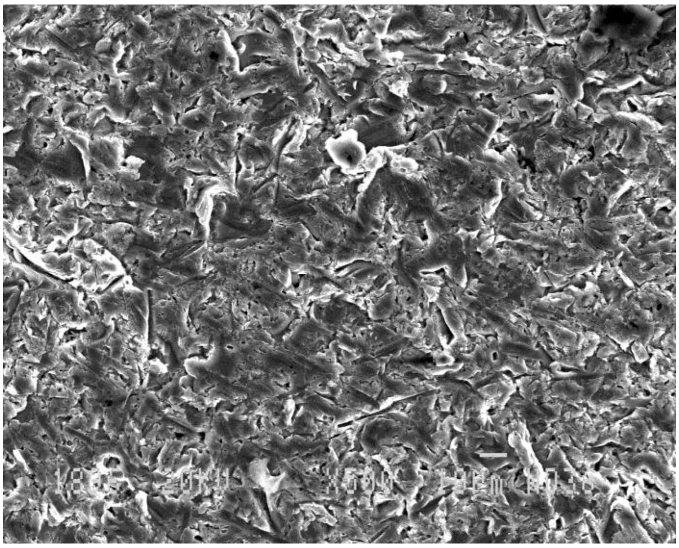
Visual inspection of breakage samples are shown in fig.8. Surface defects such as laps, seams, and fins and silver were observed in wire rod samples. Prominent surface scratches were also observed in breakage samples. The lack of proper lubrication between the wire and the die was observed. With the high die pressure and the continued appearance of unreached, nascent metal at the wire surface, a relatively strong bond develops between the wire and the die. Thus the metal sticks to the die, and the shearing action between the wire and the die involves a shearing off of the wire surface, leaving wire metal stuck in the drawing channel. In effect the emerging wire surface is a ductile fracture surface.

Crow's feet marks observed on the surface near the breaking ends of the wire causes catastrophic breakdown of the drawing operation. This is due to marginal lubrication leads to local sticking, typically long strings of chevron-like shear fractures in the wire surface commonly called "crow's feet." As this condition of local sticking become more pervasive, involving patches of shear fractures and crow's feet. During subsequent drawing operation as crow's feet marks exceed the critical limit, the wire breakage may be noticed.

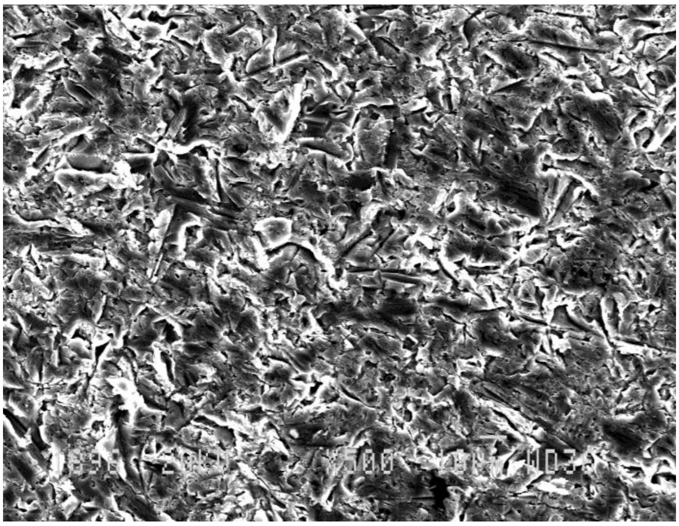
Fig. 8: Wire Breakage Samples

4.1.2 Analysis of Microscopic Examination of Wire Breaks

Aluminum is a FCC structure crystal. The difference in atomic diameters of elements like magnesium, silicon, copper and zinc are within 15% with that of aluminium. Therefore Al-Mg-Si alloy is substitutional solid solution. There were two types of precipitation observed in aluminum metals: pure precipitated metallic phases like (Al-Si-Mg, Al-Fe-Si) and precipitation of metallic elements in non-metallic inclusions such as MgO. At room temperature, α-AlFeSi particles (the matrix-grey) and small particles of Mg_2Si (black) in precipitation form were observed in specimen No.1 and specimen No.2 as shown in fig. 9. The dispersion of the second phase are well bonded with the matrix. When plastic deformation takes place, the second phase's particles readily cut by the dislocation causing slip and relatively large location. This will leads to high stresses, easy initiation of micro cracks and leads to void formation and ductile fracture



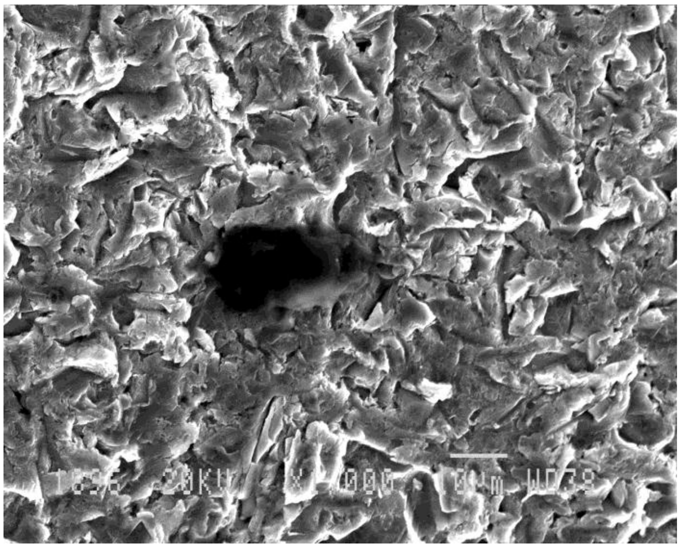
(a)



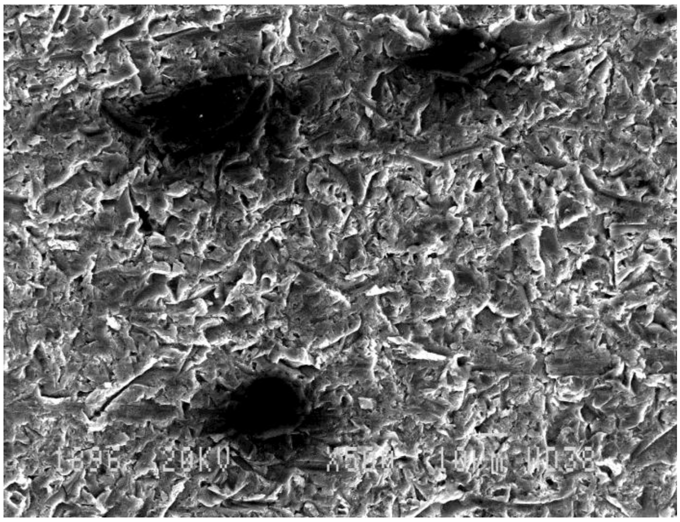
(b)

Fig. 9: Transverse Cross section of Φ7.6 mm rod
(a) Specimen 1, (b) Specimen 2

In specimen No.3 and specimen No.4 were the longitudinal cross section of incoming rod material as shows in fig. 10. It shows inclusions within the wire material. Those are black thick film elongated lumps of Al_2MgO_4 known as spinels. They result from the reaction between magnesium and oxygen in the melt during the casting process. Since spinels are very hard structure and large size, these are very harmful in the drawing process. When an inclusion passes through a die, since tensile stress acts in the drawing direction at the center of the wire, internal crack occurs at the boundary in front of the inclusion. With high drawing stresses wire may not tolerate the stress generated under this condition, the inclusion could not pass through the die, and the wire may break.



(a)



(b)

Fig. 10: Longitudinal cross section of Φ7.6mm rod
(a) Specimen No.3, (b) Specimen No.4

Un-etched surface of the wires were also observed with voids and micro cracks as in specimen No.5, 6, 7 and 8 as shown in fig. 11-14. Prominent surface scratches were observed leading to crow's feet marks in the drawn wire and the consequence of wire breakages. This indicates the lack of proper lubrication during the drawing process. These surface irregularities lead to sticking friction and cause of wire breakage

Inclusions are also observed in specimen No.9 and 10 as shown in fig. 15, 16. It may be developed during melting and alloying of aluminum in the furnace.

During continuous casting, refractory materials particles in contact with aluminum alloy can be detached and become inclusions. These include graphite inclusions (C), alumina inclusions (alpha-Al_2O_3), CaO, SiO_2 etc. Those are harder and more detrimental inclusions in the drawing process.

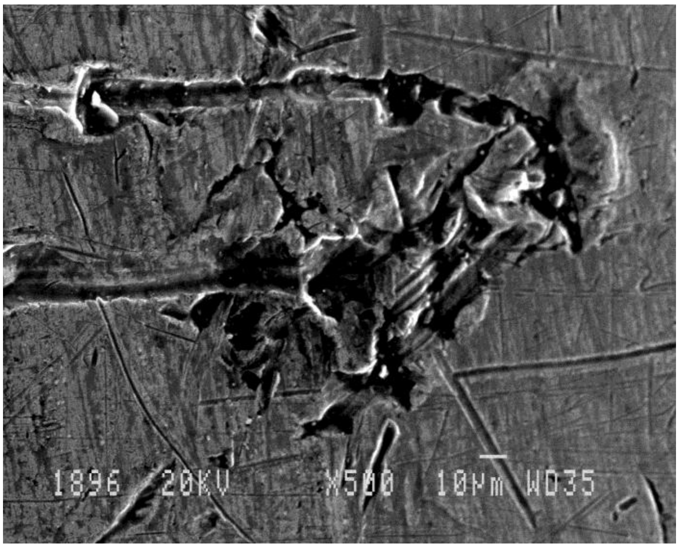


Fig. 11: Un-etched surface of wire Φ 5.06, Specimen 5

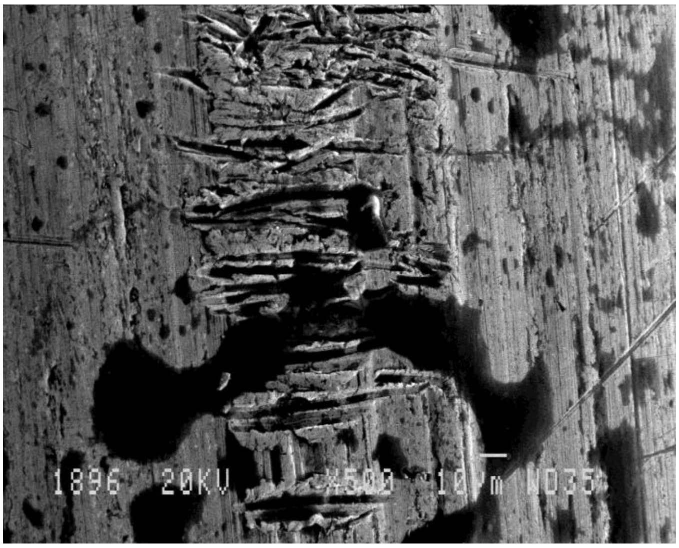


Fig. 12: Un-etched surface of wire Φ 3.58 mm Specimen 6

Fig. 13: Un-etched surface of wire Φ 4.04 mm, Specimen 7

Fig. 14: Un-etched surface of wire Φ3.15mm Specimen 8

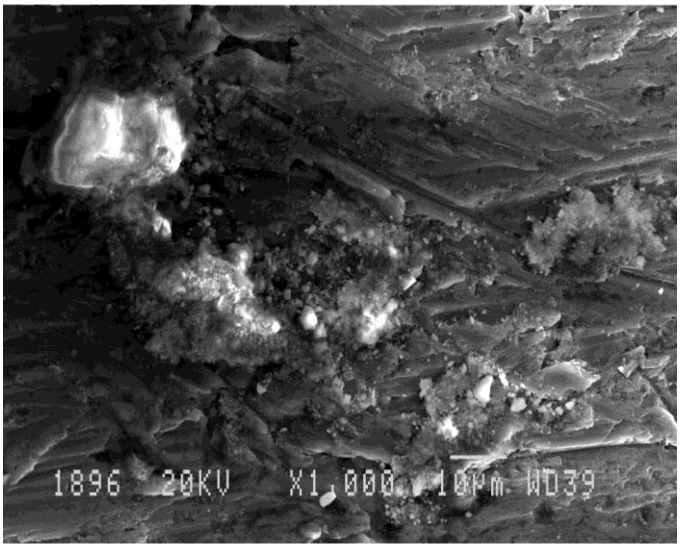


Fig. 15: Longitudinal cross section Φ 3.58 mm Specimen 9

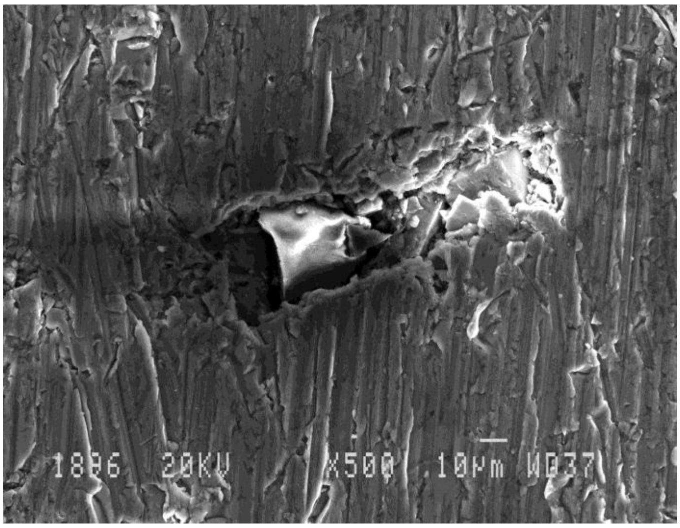


Fig. 16: Longitudinal cross section Φ 3.58mm Specimen 10

It is concluded from the above analysis that the random breakage occurs in wire drawing operation is due to the presence of inclusions present in the input wire rod to the RBD machine. Defects in wire stock such as void or inclusions are to be avoided using proper metallurgical treatment like inclusion removal process such as electro-slag refining .The defective wire rod can be monitor through an NDT testing process like any online radiography test before the rod is fed into the RBD machine.

4.2 Analysis of Tensile Failure

The plastic deformation in drawing is achieved through dies with uni-axial tension and biaxial compression. In drawing process as wire diameter goes on decreasing different stress is produced in original and final wire. The stress on the initial wire must exceed the yield strength of the metal to cause deformation and stress on the final wire must be less than its yield strength to prevent failure. This is only possible if the wire strain hardens in a controlled manner. Strain hardening occurs as plastic deformation involves the relative slip or shearing of certain planes of atoms of wire materials through dislocation motion. As plastic strain accumulates, the number of dislocations begins to multiply and dislocations per unit volume of materials increase to congestion in dislocation motion.

The ultimate tensile stress observed during tensile test in table 3 for sound wires quality go on increasing from initial die station to final die station. It is because of work hardening of the material during cold working. The fig.17 shows the strength variation in wire rod.

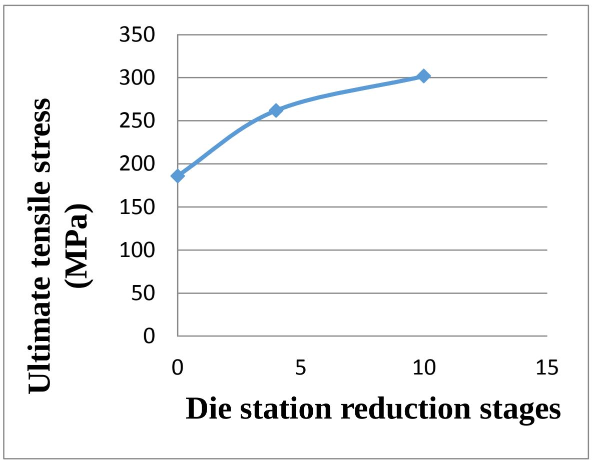


Fig. 17: Strength Variations in Sound Wire Sample

However uneven tensile strength development in between wire samples was observed during the tensile test as noted in table 3. This was due to flaws and inclusion present in the wires. Fig. 18 shows the strength variation in wire rod of samples.

Yielding and breaking are generally associated with the instability created by plastic stretching of the wire between dies. The drawing force may exceed the tensile fracture strength due to wire cross-over, misalignment between the wire and the draw die, poor lubrication, dies packed with fines or due to broken dies.

Table3: Tensile Test Values of Breakage Samples

Die station No	Diameter Φ, mm	Area of cross Section mm^2	% area reduction in each die	Total % reduction	Maximum Breaking load, KN	Ultimate Tensile Strength, MPa
2	6.38	40.70	20.60	29.52	6.65	208
3	5.69	32.38	20.46	43.25	5.80	228
4	5.06	25.60	20.92	55.67	4.83	240
5	4.51	20.34	20.56	64.78	4.19	262
6	4.02	16.16	20.55	72.02	3.70	291
7	3.58	12.82	20.69	89.18	2.84	282

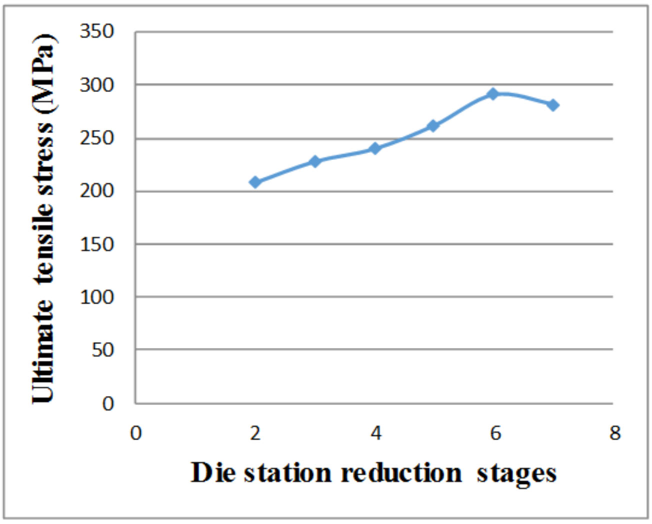


FIG. 18: Strength variations in breakage wire sample

In such cases, when the ratio of draw stress to flow stress is equal to one, wire vibration and lubricant fluctuation will be expected in the drawing operation. The co-efficient of friction between the die-wire interference will vary considerably and changes the draw stress to flow stress ratio, which should be as low as 0.7 because of anisotropic behavior of the wire material in order to prevent breakage of wire [35].

5. CONCLUSIONS

The following conclusions are drawn from the present investigation:

- During continuous casting process of 6201 Al alloy containing Mg and Si, inclusions such as magnesium oxides (MgO) and cuboids or metallurgical spinels ($MgAl_2O_4$) are formed. Such inclusions which are large in size cause breakage of the wire during drawing process. These inclusions are to be control during melting and alloying of metal with proper homogenization and filtering.

- During continuous casting, refractory material particles in contact with aluminium alloy detach and become inclusions. These include graphite inclusions (C), alumina inclusions (alpha-Al_2O_3), CaO, SiO_2 etc. Those are hard and more detrimental inclusions in the drawing process. Those hard inclusions also cause breakage during drawing operation. Removal of non-metallic inclusions from the alloys may be carried out through electro-slag refining process.

- Tensile failure analyses shows that at higher value of friction, the ratio of draw stress to that of flow stress of wire material exceed the acceptable limit of 0.7 leading to wire breakage. It is observed that for co-efficient of friction value 0.1, the ratio of draw stress to flow stress well below the acceptable limit 0.7 for all the die stations.

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