Experimental analysis of Fracture Toughness of EN9 and EN31 Steel under double layer of electroplating materials with different varied thickness

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1. Abstract
With the advent of technology, there is a need to invent newer plating to improve the strength of the material. In this paper, two materials namely Steel Grades EN9 and EN 31 are considered. These materials are having quite a good industrial applications and are being used in many machine parts manufacture. Some of the widely used applications are in the manufacture of Crank shafts, Cylinders, Gears, Sprockets, aerospace parts and body of the ships and automobile parts mainly its surfaces which require high impact resistance and also wear resistance for increased life of the components. The non-electro plated materials are also having the property of higher abrasion resistance. In this paper, the preparation of the specimen, electro plating techniques adopted for getting varied thickness and their critical characteristics in improving the property of the material are discussed further, a statistical model is proposed to obtain the bench mark for its effective implementation of these materials for its industrial use.

2. Objective
The objective is to prepare 2 specimens namely EN9 and EN31 material and to carry out electro plating operations to vary the plating thickness. Further, the IZOD and Charpy tests have to be conducted with varying notch shapes and are best suited for the industrial applications.

3. Methodology
The specimens are prepared using heat treatment process and the electro plating are done under varying cutting conditions. These specimens are cut as per the configuration/specification of IZOD and Charpy tests. Various strength parameters are checked using the impact-testing device. Mathematical models are proposed to bench mark the process parameters.

4. Set up of the specimens
The following properties are considered for the preparation of the specimen.

4.1 Mechanical properties of EN 9 & EN 31 steels
- Materials having high degree of hardness with compressive strength and abrasion resistance.
- Through proper grain flow orientation maximum impact strength and fatigue resistance. Possible in a metal.
There are no internal gas pockets or voids that may cause unexpected failure under conditions of high stress or impacting Steels Designated on the Basis of Mechanical Properties. The mechanical property of EN 9 & EN31 steels as shown in table 1

**Table 1. Mechanical property of EN9 Steel**

| Property     | Value                        |
|--------------|------------------------------|
| Max Stress   | 600-700 N/mm²                |
| Yield Stress | 310-355 N/mm² Min            |
| Hardness     | 170-255 Brinell              |

4.2. Chemical composition of EN 9 & EN31 steels:

The Chemical composition of EN 9 & EN31 steels as shown in table 2

**Table 2. Chemical composition of EN 9 & EN31 steels**

| EN STEELS | C   | Mn  | Si  | S   | P   | Cr  | Ni  | Mo |
|-----------|-----|-----|-----|-----|-----|-----|-----|----|
| EN-9      | .50 | .60 | .50 | .80 | .05 | .04 | .04 |    |
| EN-31     | .90 | 1.20| .30 | .75 | .10 | .04 | 1.00| 1.60|

4.3 Size and specification of testing specimens

4.3.1 Charpy Test Specimens

Table 3 shows the specification of Charpy test specimen.

**Table 3 Size and specification of Charpy testing specimens**

| Specifications | Details                        |
|----------------|--------------------------------|
| Size           | 55x10x10mm                     |
| Types of notch | 'V' notch and 'U' notch        |
| Depth of 'V' notch | 2mm with 0.25mm radius.      |
| Angle of 'V' notch | 45°                           |
| Depth of 'U' notch | 4.5mm with 1mm radius.      |

4.3.2 Izod specimen

The specification of Izod test specimen is selected as per ASTM standards as shown in table 4.

**Table 4 Size and specification of Izod testing specimens**

| Specifications | Details                        |
|----------------|--------------------------------|
| Size           | 75x10x10mm                     |
| Type of notch  | 'V' notch                      |
| Depth of 'V' notch | 2mm with 0.25mm radius.      |
| Angle of 'V' notch | 45°                           |

4.3.3 Making of Charpy test specimen

Fig: 1 (a), V-notch Charpy test specimens, Fig: 1 (b), U-notch Charpy test specimens
5. RESULTS AND DISCUSSION
Impact test has been carried on EN9 and EN31 Steel under different electroplating material with thickness under Normal, Nickel electroplating, Silver electroplating, Chromium electroplating and Zinc electroplating condition and the results are tabulated as follows.

5.1. SILVER ELECTROPLATING

5.1.1. Solution composition
The silver electroplating process is carried out by selection of solution. Chemical composition is as shown table 5.

| Table 5 Solution composition of silver electroplating |
|------------------------------------------------------|
| Silvermix Bright Silver Salt                         |
| Argolume Carrier Additive                            |
| Argolume Brightener                                  |
| 200.0 g/l                                            |
| 10.0 ml/l                                            |
| 30.0-40.0 ml/l                                       |

5.1.2 Operating conditions
The operating conditions of silver electroplating is shown in Table 6.

| Table 6 Operating condition during silver electroplating |
|---------------------------------------------------------|
| Cathode current density                                 |
| Anode current density                                   |
| Agitation                                               |
| Anodes                                                  |
| Temperatures                                            |
| pH (Electrometric)                                      |
| 1.0-2.5 A/dm²                                           |
| 1.0-2.5 A/dm²                                           |
| Cathode rod movement                                   |
| Pure silver                                             |
| 20-32 ºC                                                |
| 12.0-12.5                                               |

5.1.3 Solution Preparation
The silver solution was prepared in a storage tank, and then thoroughly cleaned with water. The lining of the tank, filters are leached with 10% Caustic Potash Solution and immersed in this condition for 12 hours. The tank was cleaned again with fresh water and then cleaned in deionized water. The following steps are followed for the preparation of solution,
- The auxiliary tank was filled with two-thirds full of deionised water.
- Silvermix Bright Silver Salt is added by stirring till all the salt are completely dissolved.
- Activated Carbon was added and stirred for few hours and then allowed to settle for a period of 12 hours
- This solution was filtered and, transferred to the plating tank and then deionized water is added to make up the level
- The filter unit is cleaned and filtered until the solution becomes clear.
- A calculated quantities of Argolume Carrier additive and Argolume brightener were added and stirred. The prepared solution for plating operation as shown in fig13.

Fig 2: materials before electroplating in to solution bath.
5.1.4 Plating procedure
The pre-treatment procedure before plating in Argolume process is the same as for standard silver plating. A silver strike is required to assure good bonding of silver deposits to copper, brass and copper based alloys. A Strike silver bath composition is shown in below table 7. A silver electroplating as per the double layer 2µ and 4µ is shown in the figure 14 a & 14 b.

Table 7: Strike silver bath composition.

|                        |          |
|------------------------|----------|
| Silver content         | 1.5 - 2.0 g/l |
| Free Potassium Cyanide | 100.0 g/l   |

Fig.14 (a)  
Fig.14 (b)  
Fig.3. (a): 2 micron silver electroplating of Izod and Charpy specimens.  
Fig.3. (b): 4 micron silver electroplating of Izod and Charpy specimens.

5.1.5 Deposit Thickness in Time (Based on 100% Cathode Efficiency)
The deposition of electroplating thickness of a material w.r.t. time (in min) is shown in table 8.

Table 8 Deposit Thickness Time (in min)

| Thickness (Mic) | Current density Amp/dm² with time in minutes |
|----------------|---------------------------------------------|
|                | 0.5 Amp/dm² | 1.0 Amp/dm² | 2.0 Amp/dm² | 3.0 Amp/dm² |
| 2              | 5.76        | 2.88        | 1.44        | 0.96        |
| 4              | 11.52       | 5.76        | 2.88        | 1.92        |

5.2 CHROMIUM ELECTROPLATING
5.2.1 Bath solution composition
The Chromium electroplating process is carried out by suitable selection of solution. Chemical composition is as shown table 9

Table 9 Bath solution composition of Chromium Electroplating

|                        | OPTIMUM | RANGE   |
|------------------------|---------|---------|
| Grobrite Chrome Salt   | 250 g/l | 220 - 300 g/l |
| Chrome Conducting Salt | 5 g/l   | 4 - 10 g/l    |

5.2.2 Operating conditions
For the Chromium electroplating process, the following operating condition is considered and is indicated in Table 10.
### 5.2.3 Solution Preparation

The Grobrite chrome solution was prepared with some precautions. The salt has to be dissolved completely.

The procedure to be followed in its preparation is as follows.

- The auxiliary tank was filled with two-thirds full of deionised water.
- Grobrite chrome salts are added by stirring till all the salt are completely dissolved.
- Activated Carbon was added and stirred for few hours and then allowed to settle for a period of 12 hours.
- This solution was filtered and transferred to the plating tank and then deionized water is added to make up the level.
- The filter unit is cleaned and filtered until the solution becomes clear.
- A calculated quantities of Argolume Carrier additive and Argolume brightener were added and stirred. The prepared solution for plating operation as shown in fig13.

| Table 10 Operating condition of Chromium Electroplating |
|--------------|----------|
| Density      | 19 - 23ºBe |
| Temperature  | 45 - 50°C  |
| Cathode Current Density | 10 - 30 A |
| Anode Current Density   | 5 - 15 A   |
| Voltage       | 4 - 12 volts |

**Fig 4:** materials before electroplating into solution bath.

### 5.2.4 Plating procedure

The pre-treatment procedure before plating in Chromium plating is the same as hexavalent chromium plating. A Chromium strike is required to assure good bonding of Chromium deposits to copper, brass and copper based alloys. A Strike Chromium bath composition is shown in below table 11. A Chromium electroplating as per the double layer 2µ and 4µ is shown in the figure 16 a & 16 b.
5.2.5 Deposit Thickness in Time (in min)
The deposition of electroplating thickness of a material w.r.t. time (in min) is shown in table 11.

| Thickness (Mic) | Current density Amp/dm² with time in minutes |
|-----------------|---------------------------------------------|
| 2               | 8.0 Amp/dm² | 16.0 Amp/dm² | 25.0 Amp/dm² | 31.0 Amp/dm² |
|                 | 28.0        | 12.0         | 8.0          | 6.0          |
| 4               | 56.0        | 24.0         | 16.0         | 12.0         |

5.3 Nickel Electroplating
5.3.1 Solution composition
The Nickel electroplating process is carried out by selection of solution. Chemical composition is as shown table 12.

| Bath solution composition of nickel electroplating |
|---------------------------------------------------|
| NiCl₂ Salt                                      | Optimum | Range           |
| 350 g/l                                          | 300 - 400 g/l |
| Additive 22M                                    | 6.0 ml/l  | 4 - 10 ml/l     |
| Spectra 999                                     | 0.3 ml/l  | 0.2 - 0.4 ml/l  |
| Superglo A                                      | 1.0 ml/l  | 0.8 - 1.6 ml/l  |

5.3.2 Operating condition
In Nickel electroplating process the following operating condition is maintained as per standard of electroplating is as shown in table 13.

| Operating condition of Nickel Electroplating |
|----------------------------------------------|
| Temperature                                  | Optimum | Range          |
| 55°C                                         | 50-65°C |
| pH (Electrometric)                           | 4.2     | 3.8-4.5        |
| Cathode Current Density Amp                  | 4.0     | 2.5-8.0        |
| Anode Current Density Amp                    | 2.0     | 1.0-3.0        |
| Voltage                                      | 5.5     | 4.0-12.0       |
| Agitation                                    | Low pressure air /cathode rod agitation |
| Filtration                                   | Continuous | changes per hour |
| Anodes                                       | Electrolytic nickel rolled anodes, nickel rounds in titanium anode baskets |
5.3.3 Solution preparation
Fresh Nickel solution is prepared as under

- The rubber lined tank was filled with two-thirds full of deionised water.
- Bright nickel salt is added by stirring till all the salt are completely dissolved.
- Activated Carbon was added and stirred for stir the solution vigorously for 2 hours and then allowed to settle for a period of 12 hours.
- This solution was filtered and, transferred to the plating tank and then deionized water is added to make up the level
- The filter unit is cleaned and filtered until the solution becomes clear.
- A calculated quantities of Arguleme Carrier additive and Arguleme brightener were added and stirred.

The prepared solution for plating operation as shown in fig 5.

![Figure 5: materials before electroplating in to solution bath.](image)

5.3.4 Nickel plating tank
The plating tank should be of mild steel and should be lined with an approved grade of semi hard or hard rubber. The quality of rubber is very important for good performance of solution and hence it is advisable to consult the Growel Laboratory / Local Representatives before lining the tank. Thermal lagging is recommended though not essential, as it is already insulated inside by rubber lining.

5.3.5 Plating procedure
The pre-treatment procedure before Nickel plating in Nickel plating is A Nickel strike is required to assure good bonding of Nickel deposits to copper, brass and copper based alloys. A Strike Nickel bath composition is shown in below table 11. A Chromium electroplating as per the double layer 2μ and 4μ is shown in the figure 5 a & 5 b.
5.3.6 Deposit Thickness in Time (in min)

The deposition of electroplating thickness of a material w.r.t. time (in min) is shown in table 14.

| Thickness (Mic) | 1.0 Amp/dm² | 1.5 Amp/dm² | 2.0 Amp/dm² | 2.5 Amp/dm² |
|----------------|-------------|-------------|-------------|-------------|
| 2              | 10.4        | 6.8         | 5.2         | 4.4         |
| 4              | 20.8        | 13.6        | 10.4        | 8.8         |

5.4 ZINC ELECTROPLATING PROCESS

5.4.1 Solution make-up

The Zinc electroplating process is carried out by selection of solution. Chemical composition is as shown in table 15.

| Bath solution of Zinc Electroplating | Optimum | Range          |
|-------------------------------------|---------|----------------|
| Zinalite NCZ 106 salt               | 120 g/l | 110 - 130 g/l  |
| Uniglo 2012 Brightener A            | 10.0 ml/l | 8 - 12 A ml/l |
| Uniglo 2012 Brightener B            | 2.0 ml/l | 1.5 - 2.5 ml/l |
| Uniglo 2012 Brightener C            | 2.0 ml/l | 1.5 - 2.5 ml/l |

5.4.2 Operating conditions

In Zinc Electroplating process the following operating conditions is maintained as per standards of Electroplating is as shown in table 16.

| Operating condition of Zinc Electroplating | OPTIMUM | RANGE          |
|-------------------------------------------|---------|----------------|
| Zinc Metal                                 | 10 g/l  | 7.0 - 15.0 g/l |
| Sodium Hydroxide                          | 120 g/l | 100 - 150 g/l |
| Temperature                               | 25 ºC   | 20 - 40 ºC     |
| Current Density                           | 2 Amp/dm² | 1 - 3 Amp/dm² |
| Voltage                                   | 5 Volt  | 3 - 6 Volt     |
| Current Loading                           | 0.7 Max Amp/l |
| Anode to Cathode Area                     | 1 : 1 to 2 : 1 |
5.4.3 Solution preparation
To make-up 100 litres of solution add 12 kgs. Zinicalite NCZ 106 salts.
1. To a 100 litre storage tank add about 25 litres of cold water.
2. Add the salt to the cold water. Heat is generated by the dissolution of salt and it is recommended that salt is added in small increments with continuous stirring. Wear protective clothing and shield the face when handling the salt.
3. Thoroughly stir to dissolve the solid and add slowly partial amount of water.
4. Allow this solution to settle for 2 to 3 hours and then filter the solution into the plating tank.
5. All the above procedures can be avoided while using Uniglo Make-Up solution. In this case, it is recommended to take 25 lit. of Uniglo Make-Up solution and then dilute it to 100 lit.
6. Add water to make-up for the final volume. Stir thoroughly and analyse for zinc metal and Caustic soda.
7. Add Uniglo 2012 brightener components as follows
   - Uniglo 2012 Brightener A - 10.0 ml/l
   - Uniglo 2012 Brightener B - 2.0 ml/l
   - Uniglo 2012 Brightener C - 2.0 ml/l
8. Electrolyze the bath at 0.05 amp/l for 4 to 8 hours.
9. Use the solution for normal plating, with regular brightener replenishment.

Fig 6: materials before electroplating in to solution bath

5.4.4 Plating procedure
The quality of deposit obtained depends upon the proposed pre-treatment sequence. Use of non-ionic surfactants is highly recommended throughout the preparation sequence. Frequent checks of cleaner, acid pickle concentrations and temperature are recommended. An alkaline dip containing 25 to 45 g/l of sodium hydroxide is highly recommended immediately prior to the plating tank to neutralize any acid film on the surface of the metal.
Process Sequence:
For steel, the following sequence is recommended:
Immersion clean- Groclean MS / Steelex K-20 / Metaprep Act
Pickle- Hydrochloric acid (50%) (only when necessary)
The figure 20 shows the after completion of zinc electroplating as per the double layer 2µ and 4µ.

![Figure 20](image)

**Fig. 6 (a):** 2 micron zinc electroplating of Izod and Charpy specimens.
**Fig. 6 (b):** 4 micron zinc electroplating of Izod and Charpy specimens.

### 5.4.5 Deposit Thickness in Time

The deposition of electroplating thickness of a material w.r.t. time (in min) is shown in table 17.

| Thickness (Mic) | 1.0 Amp/dm² | 1.5 Amp/dm² | 2.0 Amp/dm² | 2.5 Amp/dm² |
|-----------------|-------------|-------------|-------------|-------------|
| 2               | 7.4         | 5.8         | 4.2         | 3.4         |
| 4               | 14.8        | 11.6        | 8.4         | 6.8         |

### 5.5 Collection of Data and Analysis

The Impact test has been carried out by selection of different Electroplating materials with varied thickness of 2µ & 4µ, these specimens were prepared as per ASTME23 Standards with both ‘U’ & ‘V’ notch specimens as shown in table 18.

**Table 18: Information table of experimental work**

| Sl.no | Type of test specimen | Types of notch | Thickness of plating | Electroplating materials |
|-------|-----------------------|----------------|----------------------|--------------------------|
| 1     | Charpy (55 x10x10 mm) | U-notch        | Double layer coating with thickness of “2µ” & “4µ” | 1. Nickel (ni) 2. Silver (ag) 3. Chromium (cr) 4. Zinc (zi) |
| 2     | Izod (75x10x10 mm)    | V-notch        | Double layer coating with thickness of “2µ” & “4µ” | 1. Nickel (ni) 2. Silver (ag) 3. Chromium (cr) 4. Zinc (zi) |

The Impact test has been carried out by Charpy Impact test method by different materials condition with varied Electroplating material thickness.
There are 36 Charpy Impact test specimen is carried out to determine its Fracture Toughness strength is as shown in table 19

| Type of Notch | Material Condition | Nickel | Silver | Chromium | Zinc |
|---------------|-------------------|--------|--------|----------|------|
|               | Normal            | 2µ     | 4µ     | 2µ       | 4µ   | 2µ   | 4µ   | 2µ   | 4µ   |
| ‘U’-notch     | 2                 | 2      | 2      | 2        | 2    | 2    | 2    | 2    |
| ‘V’-notch     | 2                 | 2      | 2      | 2        | 2    | 2    | 2    | 2    |
| Total         | 4                 | 4      | 4      | 4        | 4    | 4    | 4    | 4    |

Grand total = 36 specimens

There are 18 Izod Impact test specimen is carried out to determine its Fracture Toughness strength is as shown in table 20.

| Type of Notch | Material Condition | Nickel | Silver | Chromium | Zinc |
|---------------|-------------------|--------|--------|----------|------|
|               | Normal            | 2µ     | 4µ     | 2µ       | 4µ   | 2µ   | 4µ   | 2µ   | 4µ   |
| ‘V’-notch     | 2                 | 2      | 2      | 2        | 2    | 2    | 2    | 2    |
| Total         | 2                 | 2      | 2      | 2        | 2    | 2    | 2    | 2    |

Grand total = 18 Specimens

As per ASTME23 Standards, the Normal specimens was maintained by ‘U’-notch 2 specimen & ‘V’- notch 4 specimens, in the same Electroplating materials of Nickel ‘U’-notch for 2µ is 2 testing specimens & for 4µ is 2 testing specimens, similarly for Nickel ‘V’-notch for 2µ is 4 testing specimens & for 4µ is 4 testing specimens. In the same Electroplating materials of Silver ‘U’-notch for 2µ is 2 testing specimens & for 4µ is 2 testing specimens, similarly for Silver ‘V’-notch for 2µ is 4 testing specimens & for 4µ is 4 testing specimens. In the same Electroplating materials of Chromium ‘U’-notch for 2µ is 2 testing specimens & for 4µ is 2 testing specimens, similarly for Chromium ‘V’-notch for 2µ is 4 testing specimens & for 4µ is 4 testing specimens. In the same Electroplating materials of Zinc ‘U’-notch for 2µ is 2 testing specimens & for 4µ is 2 testing specimens, similarly for Zinc ‘V’-notch for 2µ is 4 testing specimens & for 4µ is 4 testing specimens.

Total specimens used for Charpy Impact testing = 36
Total specimens used for Izod Impact testing = 18

There are total impact testing specimens = 54, as is shown in table 25.

### EXPERIMENTAL TABLE 21: Fracture toughness of different material condition

| SI no | Material condition | No of specimens | Impact energy (in J/mm²) |
|-------|--------------------|-----------------|--------------------------|
|       |                    | Trial no | Charpy test V notch | Charpy test U notch | Izod test V notch |
| 1     | normal             | 6         | 1.631 | 1.756 | 1.298 |
| 2     | nickel (2 µ)       | 6         | 2.031 | 1.767 | 1.201 |
| 3     | nickel (4 µ)       | 6         | 1.798 | 1.672 | 1.143 |

There are total impact testing specimens = 54, as is shown in table 25.
As per ASTME23 standards the normal specimen was maintained by u notch 2 specimens' v notch 4 specimens in the same electroplating material of nickel v notch for 2 microns 4 testing specimens and u notch 2 testing specimens and for 4 microns 4 testing specimens and u notch 2 testing specimens.

Electroplating material of silver v notch for 2 microns 4 testing specimens and u notch 2 testing specimens and for 4 microns 4 testing specimens and u notch 2 testing specimens electroplating material of Chromium v notch for 2 microns 4 testing specimens and u notch 2 testing specimens and for 4 microns 4 testing specimens and u notch 2 testing specimens electroplating material of zinc v notch for 2 microns 4 testing specimens and u notch 2 testing specimens and for 4 microns 4 testing specimens and u notch 2 testing specimens. As shown in table 25 and the total number of specimens are tested is 54.

5.6 CHARPY IMPACT TEST RESULTS OF ‘U’-NOTCH NORMAL, NICKEL, SILVER CHROMIUM AND ZINC 2µ SPECIMEN.

The Charpy impact test is made for ‘U’ notch double layer 2µ as per ASTME23 Standard and different electroplating materials is as shown in table 22.

Table 22: Impact strength of different electroplating materials.

| Electroplating material | Impact strength |
|-------------------------|-----------------|
| Normal                  | 1.5             |
| Nickel                  | 1.609           |
| Silver                  | 1.241           |
| Chromium                | 1.395           |
| Zinc                    | 1.417           |

![Fig 7: Effects of Impact strength versus different electroplating material of 2µ.](image-url)
Above figure represents variation of Impact strength versus different Electroplating materials. The figure reveals that the thickness of electroplating by $2\mu$ means double layer. If thickness of Electroplating material increases the Impact strength also increases. In this figure Nickel Electroplating have more Impact strength $1.609 \text{ J/mm}^2$ to other Electroplating materials, the lowest minimum Impact strength is Silver Electroplating material is $1.241 \text{ J/mm}^2$.

5.7 CHARPY IMPACT TEST RESULTS OF 'U'-NOTCH NICKEL, SILVER, CHROMIUM AND ZINC 4µ SPECIMEN.
The Charpy impact test is made for ‘U’ notch double layer $4\mu$ as per ASTM23 Standard and different electroplating materials is as shown in table 23.

Table 23: Impact strength of different electroplating materials.

| Electroplating material | Impact strength |
|-------------------------|-----------------|
| Normal                  | 1.5             |
| Nickel                  | 2.1             |
| Silver                  | 1.58            |
| Chromium                | 2.086           |
| Zinc                    | 1.702           |

Fig 8: Effects of Impact strength versus different electroplating material of $4\mu$.

Above figure represents variation of Impact strength versus different Electroplating materials. The figure reveals that, the thickness of electroplating by $4\mu$ means double layer. If thickness of Electroplating material increases the Impact strength also increases. In this figure Nickel Electroplating have more Impact strength $2.1 \text{ J/mm}^2$ to other Electroplating materials, the lowest Impact strength is Normal material is $1.5 \text{ J/mm}^2$.

5.8 CHARPY IMPACT TEST RESULTS OF 'V'-NOTCH NICKEL, SILVER, CHROMIUM AND ZINC 2µ SPECIMEN.
The Charpy impact test is made for ‘V’ notch double layer $2\mu$ as per ASTM23 Standard and different electroplating materials is as shown in table 24.

Table 24: Impact strength of different electroplating materials

| Electroplating material | Impact strength |
|-------------------------|-----------------|
| Normal                  | 1.83            |
| Nickel                  | 1.941           |
| Silver                  | 1.894           |
| Chromium                | 1.709           |
| Zinc                    | 1.86            |
Fig 9: Effects of Impact strength versus different electroplating material of 2µ.
Above figure represents variation of Impact strength versus different Electroplating materials. The figure reveals that the thickness of electroplating by 2µ means double layer. If thickness of Electroplating material increases the Impact strength also increases. In this figure Nickel Electroplating have more Impact strength 1.941 J/mm² to other Electroplating materials, the lowest Impact strength is Chromium Electroplating material is 1.709 J/mm².

5.9 CHARPY IMPACT TEST RESULTS OF 'V'-NOTCH NICKEL, SILVER CHROMIUM AND ZINC 4µ SPECIMEN.
The Charpy impact test is made for ‘V’ notch double layer 4µ as per ASTME23 Standard and different electroplating materials is as shown in table 25.

| Electroplating Materials | Impact Strength in J/mm² |
|--------------------------|--------------------------|
| Normal                   | 1.83                     |
| Nickel                   | 2.605                    |
| Silver                   | 1.924                    |
| Chromium                 | 1.825                    |
| Zinc                     | 2.243                    |

Fig 10: Effects of Impact strength versus different electroplating material of 4µ.
Above figure represents variation of Impact strength versus different Electroplating materials. The figure reveals that the thickness of electroplating by 4µ means double layer. If thickness of Electroplating material increases the Impact strength also increases. In this figure Nickel Electroplating
have more Impact strength 2.605 J/mm² to other Electroplating materials, the lowest Impact strength is Chromium Electroplating material is 1.825 J/mm².

5.10 IZOD IMPACT TEST RESULTS OF 'V'-NOTCH NICKEL, SILVER CHROMIUM AND ZINC BY 2µ SPECIMEN.
The Izod impact test is made for ‘V’ notch double layer 2µ as per ASTME23 Standard and different electroplating materials is as shown in table 26.

Table 26: Impact strength of different electroplating materials

| Electroplating material | Impact strength |
|-------------------------|-----------------|
| Normal                  | 1.249           |
| Nickel                  | 1.163           |
| Silver                  | 1.223           |
| Chromium                | 1.284           |
| Zinc                    | 1.073           |

Fig 11: Effects of Impact strength versus different electroplating material of 2µ.
Above figure represents variation of Impact strength versus different Electroplating materials. The figure reveals that the thickness of electroplating by 2µ means double layer. If thickness of Electroplating material increases the Impact strength also increases. In this figure Chromium Electroplating have more Impact strength 1.284 J/mm² to other Electroplating materials, the lowest Impact strength is Zinc Electroplating material is 1.073 J/mm².

5.11 IZOD IMPACT TEST RESULTS OF 'V'-NOTCH NICKEL, SILVER CHROMIUM AND ZINC BY 4µ SPECIMEN.
The Izod impact test is made for ‘V’ notch double layer 4µ as per ASTME23 Standard and different electroplating materials is as shown in table 27.

Table 27: Impact strength of different electroplating materials

| Electroplating material | Impact strength |
|-------------------------|-----------------|
| Normal                  | 1.249           |
| Nickel                  | 1.52            |
| Silver                  | 1.513           |
| Chromium                | 1.538           |
| Zinc                    | 1.461           |
Above figure represents variation of Impact strength versus different Electroplating materials. The figure reveals that the thickness of electroplating by 4µ means double layer. If thickness of Electroplating material increases the Impact strength also increases. In this figure Chromium Electroplating have more Impact strength 1.538 J/mm² to other Electroplating materials, the lowest Impact strength is Normal material is 1.249 J/mm².

5.12 CHARPY IMPACT TEST RESULTS OF 'U'-NOTCH NICKEL, SILVER CHROMIUM AND ZINC BY 2µ & 4µ SPECIMEN.

The Charpy impact test is made for ‘U’ notch double layer 2µ and 4µ as per ASTME23 Standard and different electroplating materials and a combined test result is obtained as shown in table 28.

| Electroplating material | 2µ Impact strength | 4µ Impact strength |
|-------------------------|--------------------|--------------------|
| Normal                  | 1.5                | 1.5                |
| Nickel                  | 1.609              | 2.1                |
| Silver                  | 1.241              | 1.58               |
| Chromium                | 1.395              | 2.086              |
| Zinc                    | 1.417              | 1.702              |

Above figure represents variation of Impact strength versus different electroplating material by 2µ & 4µ conducting Charpy test for ‘U’ notch. Above figure reveals that increase the thickness of electroplating material, impact strength is also increases. In this figure 4µ Electroplating material having more Impact strength compared to 2µ electroplating material. Here the Nickel electroplating material having more impact strength compared to other materials, in the same way 4µ electroplating material

Fig 12: Effects of Impact strength versus different electroplating material of 4µ.

Table 28: Impact strength of different electroplating materials

Charpy test specimen for 'U'-notch by 2µ & 4µ
nickel having more impact strength of 2.1 J/mm² to other Electroplating materials, the lowest Impact strength is Silver Electroplating of 2µ is 1.241 J/mm².

5.13 CHARPY IMPACT TEST RESULTS OF ‘V’-NOTCH NICKEL, SILVER CHROMIUM AND ZINC BY 2µ & 4µ SPECIMEN.

The Charpy impact test is made for ‘V’ notch double layer 2µ and 4µ as per ASTME23 Standard and different electroplating materials and a combined test result is obtained as shown in table 29.

Table 29: Impact strength of different electroplating materials

| Electroplating material | 2µ   | 4µ   |
|------------------------|------|------|
| Normal                 | 1.83 | 1.83 |
| Nickel                 | 1.941| 2.605|
| Silver                 | 1.894| 1.924|
| Chromium               | 1.709| 1.825|
| Zinc                   | 1.86 | 2.243|

Fig 14: Effects of Impact strength versus different electroplating material of 2µ & 4µ.

Above figure represents variation of Impact strength versus different Electroplating material by 2µ & 4µ conducting Charpy test for ‘V’ notch. Above figure reveals that increase the thickness of electroplating material, impact strength is also increases. In this figure 4µ Electroplating material having more Impact strength compared to 2µ electroplating material. Here the Nickel electroplating material having more impact strength compared to other materials. In the same way 4µ electroplating material nickel having more impact strength of 2.605 J/mm² to other Electroplating materials, the lowest Impact strength is Chromium Electroplating of 2µ is 1.709 J/mm².

5.14 IZOD IMPACT TEST RESULTS OF ‘V’-NOTCH NICKEL, SILVER CHROMIUM AND ZINC BY 2µ & 4µ SPECIMEN.

The Izod impact test is made for ‘V’ notch double layer 2µ and 4µ as per ASTME23 Standard and different electroplating materials and a combined test result is obtained as shown in table 30.

Table 30: Impact strength of different electroplating materials

| Electroplating material | 2µ   | 4µ   |
|------------------------|------|------|
| Normal                 | 1.249| 1.249|
| Nickel                 | 1.163| 1.52 |
| Silver                 | 1.223| 1.513|
| Chromium               | 1.284| 1.538|
| Zinc                   | 1.073| 1.461|
Fig 15: Effects of Impact strength versus different electroplating material of 2µ & 4µ

Above figure represents variation of Impact strength versus different Electroplating material by 2µ & 4µ conducting Izod test for ‘V’ notch. Above figure reveals that increase the thickness of electroplating material, impact strength is also increases. In this figure 4µ Electroplating material having more impact strength compared to 2µ electroplating material. Here the Chromium electroplating material having more impact strength compared to other materials, in the same way 4µ electroplating material Chromium having more impact strength of 1.538 J/mm² to other Electroplating materials, the lowest Impact strength is Zinc Electroplating of 2µ is 1.073 J/mm².

5.15 Summary representation of different electroplating material with different thickness

| Electroplating material | CHARPY 'U'-notch 2µ | CHARPY 'U'-notch 4µ | CHARPY 'V'-notch 2µ | CHARPY 'V'-notch 4µ | IZOD 'V'-notch 2µ | IZOD 'V'-notch 4µ |
|-------------------------|---------------------|---------------------|---------------------|---------------------|------------------|------------------|
| Normal                  | 1.5                 | 1.5                 | 1.83                | 1.83                | 1.249            | 1.249            |
| Nickel                  | 1.609               | 2.1                 | 1.941               | 2.605               | 1.163            | 1.52             |
| Silver                  | 1.241               | 1.58                | 1.894               | 1.924               | 1.223            | 1.513            |
| Chromium                | 1.395               | 2.086               | 1.709               | 1.825               | 1.284            | 1.538            |
| Zinc                    | 1.417               | 1.702               | 1.86                | 2.243               | 1.073            | 1.461            |

Fig 16: Effects of impact strength versus different electroplating material with varied thickness in microns

The above figure represents the variation of impact strength versus different electroplating materials and different coating conditions 2µ and 4µ for ‘U’ and ‘V’ notch specimen. Above figure reveals that Nickel having more strength by double layer compared to the other 2µ electroplating materials that means in 4µ double layered Nickel having more impact strength 2.605 J/mm² (4µ), in Zinc electroplating material...
having least impact strength 2.243 J/mm² (4µ), compared to 2µ Nickel having impact strength 1.94 J/mm² and least impact strength of 2µ is Zinc it means 1.073 J/mm² The overall summary of figure represents Nickel having more impact strength than other electroplating material but least impact strength is Zinc electroplating material.

CONCLUSIONS

• Since fracture toughness behaviour of mode I is similar to the behaviour of impact energy. We can say Charpy impact testing is the best method for determination of fracture toughness of EN 9 & EN 31 grade steels both the Martials having higher corrosion resistance.
• As increases the electroplating thickness from 2 microns to 4 microns (double layers) impact strength is increases.
• As electroplating of thickness decreases its impact strength is also decreases.
• Since thickness of 4µ electroplating material having more fracture toughness value compared to thickness 2µ electroplating material.
• Up to critical value of thickness EN 9 & EN 31 graded steel can be best used as structural material for aerospace, marine, automobiles and other engineering applications

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