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Disulfide bonds modified epoxy resins: mechanical, adhesion and wear properties

ABSTRACT

Epoxy occupiesan important place in many engineering applications, so it is necessary to improveits properties such as adhesion strength, wear resistance, and toughness. In this study,epoxy was modified by incorporation of disulfide bonds. A coating layer was prepared by adding ethanol disulfideto epoxy resin at various weight percent: 0.5, 1.5, 2.5 and 3.5 wt.%. Fourier-transform infrared spectroscopywas employed to investigate any chemical interaction. Differential scanning colometry (DSC) analysis provides valuable information aboutthermal behaviour of the prepared epoxy coating. Tensile, hardness, impact, fracture toughness, and adhesion properties were tested. Wear behaviour was investigated by pin-on-disc device. Results show that epoxy containing disulfide bonds (EP+SS) offering excellent impact resistance with good fracture toughness compared to neat epoxy. Additionally, contact angle test results show an enhancement of wettability between the modified epoxy coating layer and steel substrate. Adhesion strength of epoxy layeenhanced by incorporating ethanol disulfide into epoxy resin reaching a superior value. Comparisonto neat epoxy, the coefficient of friction of (EP+SS) highly decreased reaching about 89% and wear rate decreased by 76% as the percentage of the added ethanol disulfide increases.

A tough superior adhesive epoxy coating layer was synthesised by incorporation of the ethanol disulfide compound into epoxy resin.

Key words: disulfide, epoxy, wear, adhesion, dynamic bonds.

1. INTRODUCTION

Epoxy resins have become ubiquitous in modern civilisation, appearing in everything from automobiles to aeroplanes, indoor decoration to household appliances, and biological technology to factory equipment [1-3]. Therefore, it is necessary to improve the properties of epoxy, such as mechanical properties, adhesion, and wear resistance [4-7]. Disulfide bond-modifying epoxy resins have attracted a lot of interest because of their distinctive characteristics, which include mechanical strength and the ability to heal themselves. Disulfide linkages are usually added to the epoxy network, which increases its flexibility and permits dynamic exchange processes [8]. Dutta and Karak showed that because the disulfide bonds are dynamic, epoxy vitrimers containing disulfide show remarkable elongation at break and self-healing efficiencies of up to 71.48% [9]. Similar to this, Zhang et al. found that epoxy with different disulfide bond contents had better mechanical properties [10]. With a remarkable 98% healing efficiency, Li et al. further highlighted the importance of disulfide bonds in improving self-healing performance under mild conditions [11]. Achieving strong adhesion at polymer/metal interfaces is a major challenge in interface engineering, as it is necessary for many technical applications.Tsai et. al. (2020) tried to improve the adhesive properties of epoxy by using epoxy containing aromatic disulfide links as adhesives. The disulfide system comprised bis (4-glycidyloxyphenyl) disulfide (BGPDS) and dithiodianiline (DTDA) as the epoxy monomer and diamine hardener, respectively. Exchangeable disulfide bond-epoxy resins have improved

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mechanical and thermal resilience. A high density of disulfide bonds was incorporated to speed up the exchange process, which increased the chance of bond cleavage and rearrangement and improved adhesion [12]. Krishnakumar et. al. showed how to create epoxy vitrimers containing graphene oxide (GO) and 2-aminophenyldisulfide (2-AFD) assisted polydimethylsiloxane (PDMS) that show a decrease in glass transition temperature and storage modulus with an increase in flexural strain [5]. Luzuriaga et. al. chose 4-aminophenyldisulfide (AFD) as a dynamic hardener for epoxy resin. The "dynamic" epoxy resin used to manufacture fiber-reinforced polymer composites exhibits good mechanical strength along with recycling, and re-processability [13]. Henriksen et. al. added a bio-based disulfide additive (2-hydroxyethyldisulfide) to a commercial epoxy, the result was a cross-linked polymer that is safe for the environment to fractionate. In addition, it was shown that, when compared to commercial epoxy, modified epoxy matrices with minimal addition concentrations have comparable mechanical and thermal properties [14].

This study seeks to enhance the properties of epoxy by incorporating ethanol disulfide as a modifying compound. The effect of adding ethanol disulfide to epoxy resin on the mechanical, adhesion, and wear properties was investigated. Ethanol disulfide represents an alternative cheap disulfide bond-containing compound compared to the expensive amino phenyl disulfide compound.

2. EXPERIMENTAL PART

2.1 Materials

The selected epoxy resin and hardener for this study was Sikadur 52 bis phenol-A liquid epoxy resin and its aliphatic amine hardener, mixing ratio: 2:1, which purchased from Sikadur company, Turkey. 2-Hydroxyethyldisulfideor as known 2,2′-Dithiodiethanol or Bis(2-hydroxyethyl) disulfide, has linear formula: $HOCH_2CH_2SSCH_2CH_2OH$ with molecular weight of 154,25 g/mol. It has a clear, viscous liquid appearance with dark yellow colour.Melting point range: 25 - 27 °C, boiling point and boiling range158 - 163 °C and flash point at 112 °C. 2-Hydroxyethyldisulfide was made in Switzerland and purchased by Sigma-Aldrich.

2.2. Characterization and test methods

2.2.1. Fourier-transform infrared spectroscopy (FTIR)

FTIR spectroscopydetermines the distinct wavelengths at which a sample absorbs infrared radiation, enabling the identification of the sample's functional groups. FTIR was employed to characterize the chemical composition of the prepared specimens and investigate any chemical interaction using instrument type (IR Affinity-1, Japan) with spectra range 400-4000 cm^{-1}.Using a mortar and pestle, a small amount of the epoxy compositions was ground into an extremely fine powder, the sample was then transferred to potassium bromide (KBr) discs. The two discs were pressed together to create a film, plate holders were used to support the disc in the spectrometer and snugly fitted into spectrometer and fitted directly into the path of the infrared radiation. Finally, FTIR spectrum was presented in a diagram between the transmittance intensity (T%) and wavelengths (cm^{-1}).

2.2.2. Differential Scanning Calorimetry (DSC)

DSC analysis is a powerful thermo-analytic technique that provides valuable information aboutthermal behaviour and properties of materials. It provides quantitative measurement of heat flow associated with phase transitions and chemical reactions in the sample such as glass transition temperature (T_g) and curing process. A small sample (10 mg) was placed in a closed crucible, then the crucible was inserted into a temperature-controlled cell along with an empty reference crucible. The sample underwent a controlled heating, and the heat flow was monitored and analysed. DSC test was done using the SH1MADZ-4 DSC-60 device. The operating conditions were: 25- 250 °C temperature range with10 °C/min heating rate under argon gas environment.

2.2.3 Scanning Electron Microscope (SEM)

The American SEM device, FEI model, was employed to investigate the microstructure of coatings and the fracture surface of tensile specimens. The epoxy samples must be coated with ultrathin gold layer to be conductive.

2.2.4. Tensile test

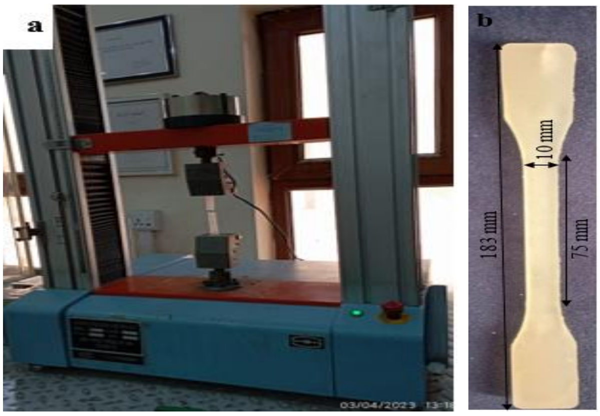
The WDW-5E electronic universal testing machine was used for tensile strength test, using a 5 N load cell and a 5 mm/min cross headon ASTM D-638-14 [15]. Figure 1 shows the test process and specimen dimensions. The sample was firmly clamped by the machine grips to prevent any slippage during the test then the sample was subjected to a gradually increased axial force until rapture. The applied load and the corresponding deformation were continuously recorded to get the stress-strain curve [16]. The values of stress, strain, and modulus of elasticity were calculated according to the following equations:

$$\sigma = P/A \tag{1}$$

$$\varepsilon = \Delta L/L \tag{2}$$

$$E = \sigma_2 - \sigma_1 / \varepsilon_2 - \varepsilon 1 \tag{3}$$

Where: σ: tensile strength (MPa), *P*: applied load (N), *A:* cross-sectional area (mm^2), E: modulus of elasticity (MPa).



a) b)

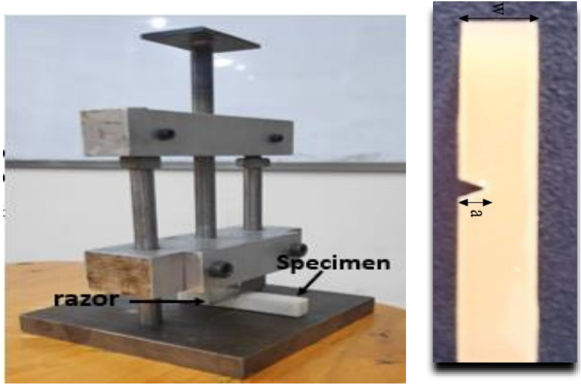
Figure 1. a) tensile strength test, b) specimen dimensions

2.2.5. Hardness test

A hardness test measures a material's resistance to indentation. The device is made-up of instrument with a calibrated and an indenting probe. The probe with conical-shaped tip is made of hardened steel or carbide. By perpendicular pressing the durometer probe on to the specimen surface, the device measures the depth of interpenetrating trace to get the value of hardness ranging from 0 to 100. A Shore D durometer instrument (TIME 5431 model, China) was used to test cylindrical specimens with at least 3 mm thickness, following ASTM (D2240) standards [17]. The surface of each specimen was tested six times, with the final hardness being an average of the results.

2.2.6. Fracture toughness test

A single edge-notched three-point bending test (SENB) was conducted on V-shaped notch bars of 53 mm long, 9 mm wide, 8 mm thickness with 36 mm support span length and 10 mm/min loading rate, using a universal testing machine type (WDW/5E) at 5 KN, following the ASTM D5045-14 procedure. Three accurate measurements were taken to confirm data dependability, and critical stress intensity factors (K_{IC}) were analysed.



(a) (b)

Figure 2. a) The process of creating incisions within SENB fracture toughness specimen, (b) SENB specimen

Before testing, the specimens should be pre-cracked at the tip of v-sectionand the so called " sharp crack introduced by the razor" was created by applying a weight with hand force on the razor at the tip of v-section as shown in figure 2. Finally, the stress intensity (K_{IC}) was calculated by Eq.4:

$$KIC = \frac{P}{B\sqrt{W}} f\left(\frac{a}{W}\right) \qquad (4)$$

$$f\left(\frac{a}{w}\right) = \frac{\left(2+\frac{a}{w}\right)\left\{0.886 + 4.64\left(\frac{a}{w}\right) - 13.32\left(\frac{a}{w}\right)^2 + 14.72\left(\frac{a}{w}\right)^3 - 5.6\left(\frac{a}{w}\right)^4\right\}}{\left(1-\frac{a}{w}\right)^{3/2}} \qquad (5)$$

Where: K_{IC}: fracture toughness (Stress Intensity Factor in Mode I) (MPa · $m^{1/2}$), P: maximum load (N), B: thickness of the specimen (mm), W: width of thespecimen (mm), a: crack length (mm) and f (a/w): shape factor.

2.2.7. Impact test

The WP 400 model, a German machine from HAMBURG, was used to test the impact strength of specimens using the Charpy test method basing on ISO 179. A rectangular bar was horizontally supported by two anvils then the pendulum of the machine test was released to a highest height and free felled to hit the specimen causing fracture. Then the energy absorbed by the specimen during fracture was measured.The impact strength (a_{cU}) was determined by calculating the necessary energy for fracture using a formula on an unnotched specimen (Eq. 6). Figure 3 shows the dimensions of specimen required for impact test.

$$acU = \frac{WB}{bh} * 10^3 \qquad (6)$$

Where: a_{cU}: impact strength (J/mm^2), h: thickness (mm), b: width (mm), W_B: energy at break (joule).

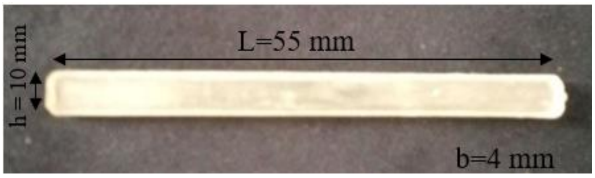


Figure 3. The dimensions of specimen required for impact test

2.2.8. Wear test

Using a pin-on-disk device, ASTM G99-17 describes the test method outlines of laboratory process for assessing material wear during sliding [18]. Wear test was accomplished utilizing a pin-on-disc machine (U.S.A. MT4003, version 10) where under a load of 15N, a disc of epoxy specimen (40 mm diameter and 4mm thickness) was rotated in a circular path with 250 rpm speed, sliding distance of approximately 235 m for 30 minutes on a stationary steel pin (6 mm diameter, HRC 56 hardness and 3.2 surface roughness) as shown in figure 4. Wear rate was calculated by Eq. 7.

$$\text{Wear rate\%} = \left(\frac{\Delta w}{w^{\circ}}\right)*100 \qquad (7)$$

Where:

Δw : weight difference of a specimen before and after wear test (g).

w° : weight of a specimen before wear test(g).

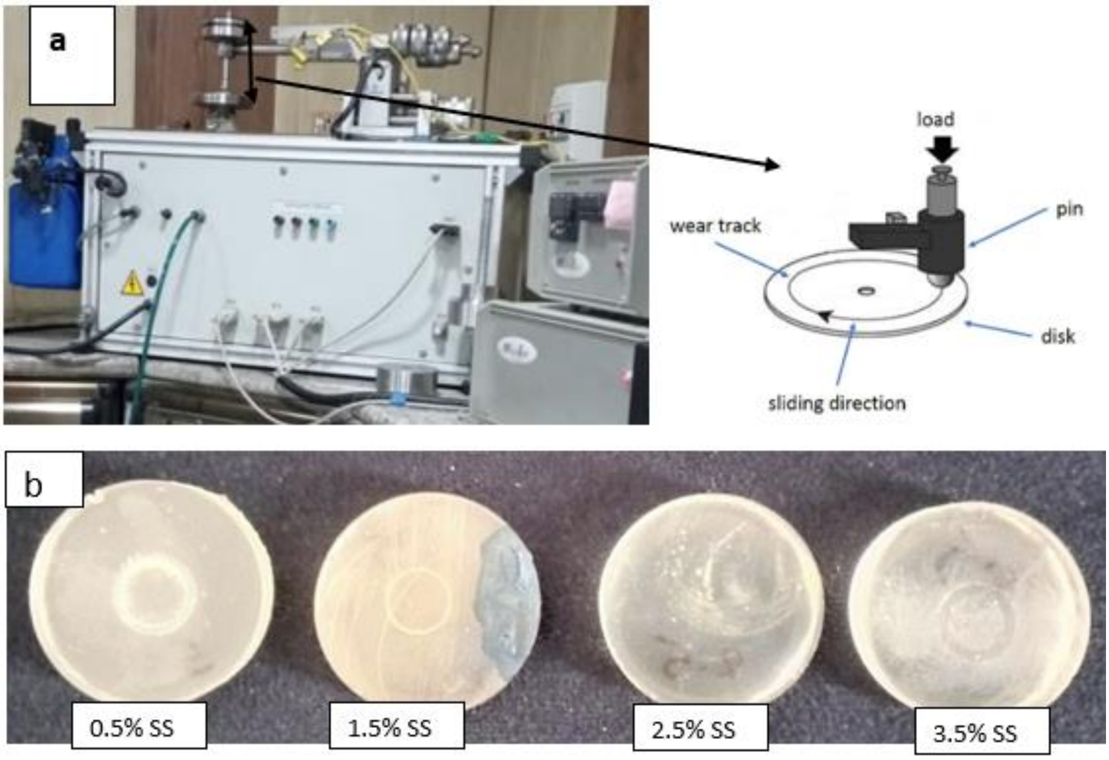


Fig.4: a) pin-on-disc wear test, b) EP+SS samples

2.2.9. Contact angle test

Microliter-sized droplets are applied to a sample surface in order to determine the contact angle (C.A.). A surface's wettability is determined by the contact angle, which is the angle produced at the droplet's boundary. Additionally, contact angle measurement can provide a useful information about surface free energy, surface tension, and work of adhesion. C.A of neat epoxy coating (EP) and that of epoxy-ethanol disulfide coatings (EP+SS) on steel surfaces was measured. Additionally, C.A between water droplet and those coatings was measured. Vino for contact angle meter, China, device was used.

2.2.10. Pull-off strength test

A typical technique for evaluating coating and adhesive quality is the pull-off test, which involves gluing a dolly to a substrate (metal), as illustrated by ASTM D-4541. Next, by drawing perpendicular to the surface, the dolly and the adhesive or coating are removed from the substrate then the required force to pull-off the coating from the substrate surface divided by the contact area represents the pull-off strength (adhesion strength) of coating. The surface of a steel screws with a diameter of 17 mm was prepared by grinding and cleaning well with acetone to adhere well to the coating layer. A sufficient vertical pulling force was applied to remove the coating layer from the surface of steel substrate using the tension device (WDW-5E electronic universal testing machine), then the adhesion force was calculated. Figure 5 shows the test technique.

$$\text{Adhesion strength} = \frac{f}{contact\ area} \qquad (8)$$

where: *f*: pulling force (KN).

Contact is the contact area between dolly surface and coating layer (227 mm^2).

The adhesion strength and percentage improvement of adhesion strength were calculated according to Eq. 8 and 9, respectively.

$$Improvement\% = \left(\frac{Sm - S_0}{S_0}\right) * 100 \qquad (9)$$

where: *Sm*: adhesion strength of modified epoxy (MPa) and *S$_0$*: adhesion strength of neat epoxy (MPa).

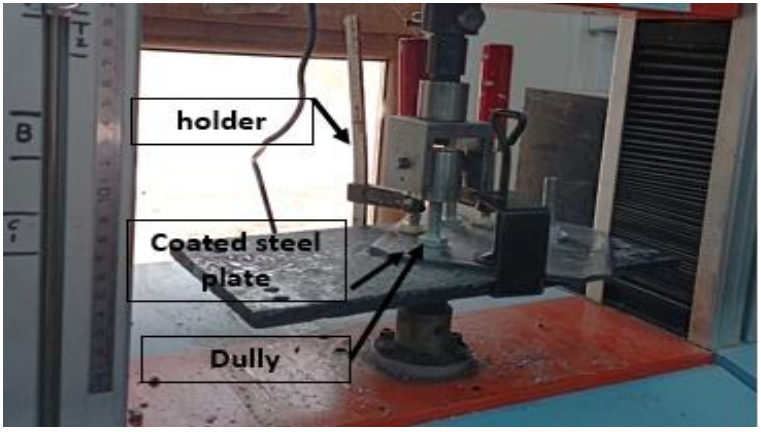


Figure 5. the pull-off test

3. RESULTS AND DISCUSSION

3.1. Fourier-Transform Infrared Spectroscopy (FTIR)

From analysing FTIR spectrum (Figure 6: a), it is clear that a complete curing of epoxy was satisfied by disappearance of peak at 910 cm^{-1}, which corresponded to C-O stretching in oxirane ring and 3056 cm^{-1} for C-H stretching of the oxirane ring, that served as a sign that the curing process was finished [13]. Additionally, FTIR spectroscopy was used to characterise all EP+SS with varying ethanol disulfide concentrations. Comparing with the spectrum of the reference sample (neat epoxy), we notice the emergence of a peak at 509 cm^{-1} for the epoxy samples modified with the addition of ethanol disulfide. This may indicate the incorporation of the S-S bond into epoxy structure [19]. Furthermore, it is possible to conclude that increasing the intensity of FTIR peaks for EP+SS samples represents an increment of functional groups or interaction between the functional groups.

The additives should have at least two functional groups, that can operate as affective nucleophiles, e.g., amines, alcohols, carboxylic acids and so on. 2-hydroxyethyldisulfide(ethanol disulfide) has two functional sites**,** or reaction sites, at the OH group as illustrated in Figure 6b.

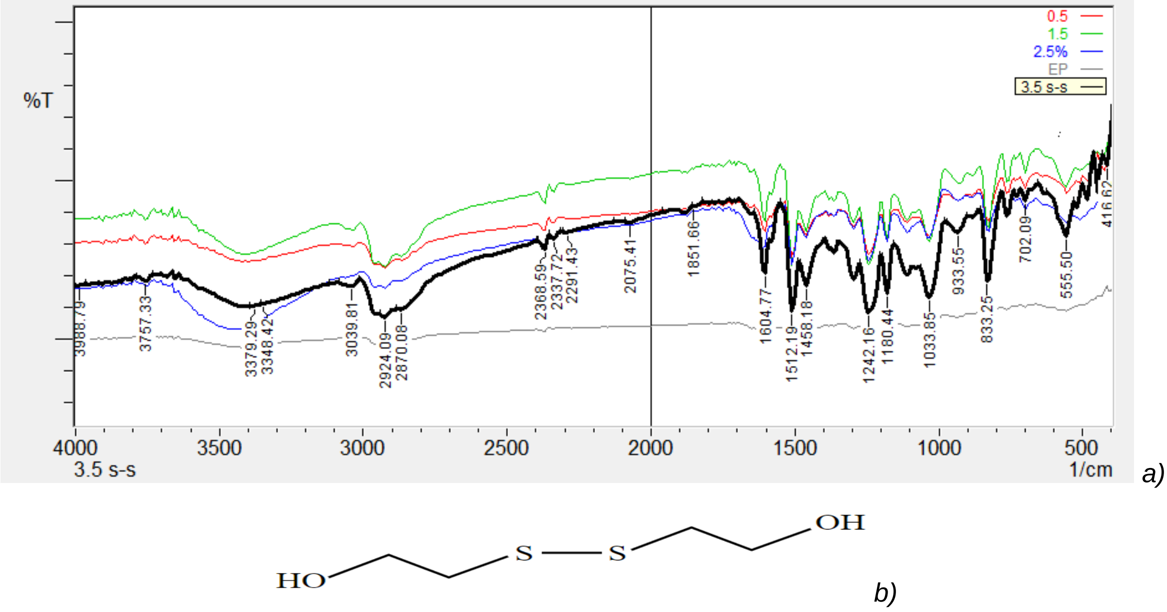


Figure 6. a) FTIR spectrum, b) chemical structure of 2-hydroxyethyldisulfide

3.2. Differential Scanning Calorimeter (DSC)

The polymer network's cross-linking density rises in tandem with the degree of cure, limiting molecular mobility and thus increasing the measured T_g. From analysing the results of DSC test, it is found that a high regression of T_g values of EP+SS compared to neat epoxy (see Table 1).

Table 1. DSC thermograms for the neat epoxy and EP+SS.

Sample	0	0.5	1.5	2.5	3.5
Tg (ºC)	80	65.5	63.4	64	63.6

3.3. Mechanical Properties

Figure 7 shows the change of the epoxy mechanical properties when different percentages of ethanol disulfide were added to it. It is clear that a regression of tensile and hardness properties has been occurred, whereas a raising of toughness properties has been occurred. It is found that as ethanol disulfide content increases up to 3.5%, the tensile strength of epoxy decreases by about 26%. The percentage elongation of neat epoxy reaches to 2%, whereas it reaches to 22% at 3.5 wt.% of ethanol disulfide adding. Epoxy hardness decreases by about 19 to 45% when 0.5% to 3.5% of ethanol disulfide were added to epoxy resin.

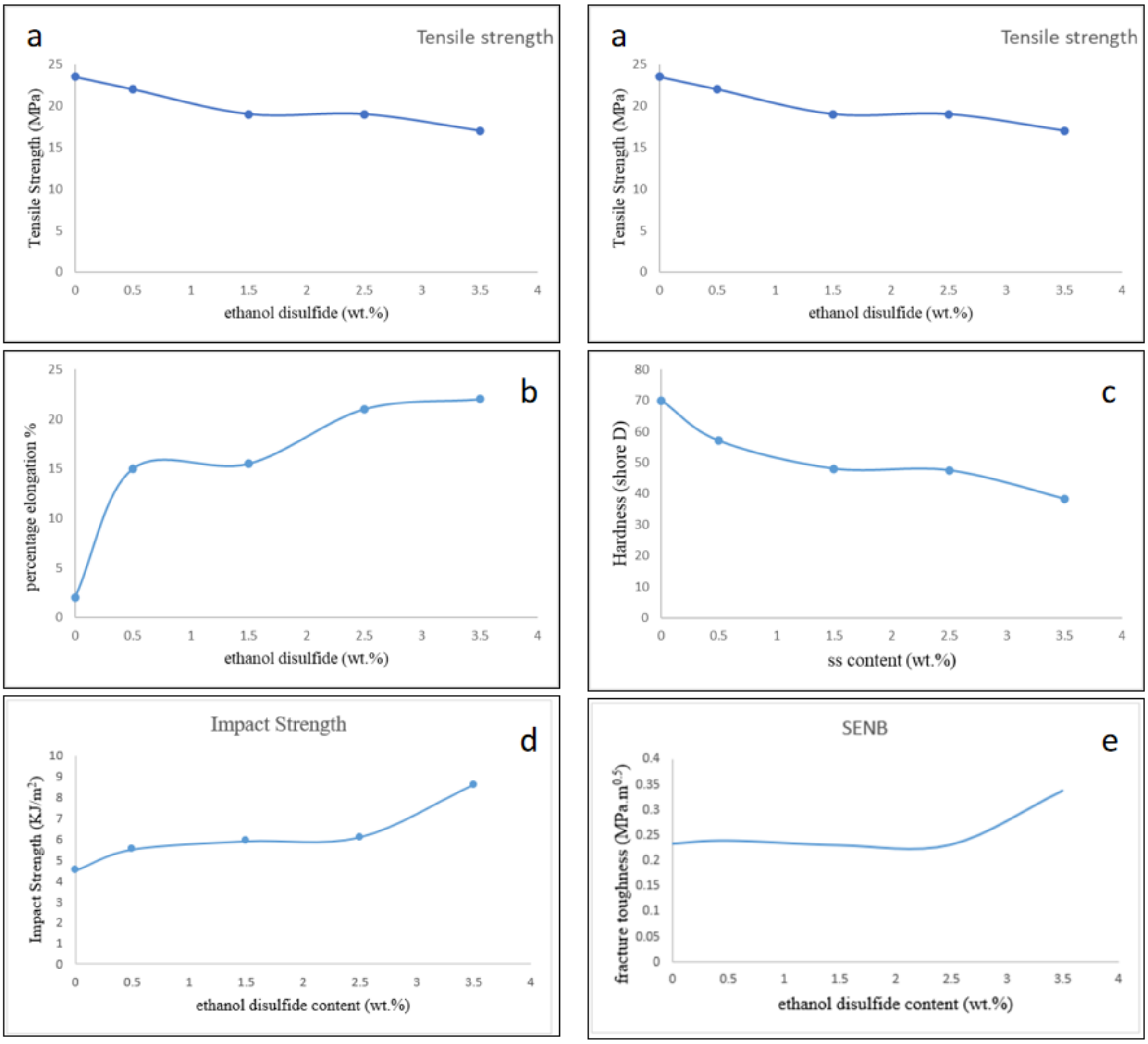


Figure 7. The principle mechanical properties of epoxy containing ethanol disulfide: a) tensile strength, b) percentage elongation at break, c) shore D hardness, d) impact strength and e) SENB

The primary disadvantage of cured epoxy is its extreme brittleness, which demonstrates low fracture toughness or low resistance to crack initiation and propagation. Epoxy using in various industries needing high fracture strengths, including matrix resins for composites, has been restricted due to their intrinsic brittleness. Therefore, ethanol disulfide is used as modifier to improve toughness property of epoxy.

For neat epoxy, the values of impact resistance and $K_{IC}$are found as ~449.7 J/m^{2}and ~0.234 MPa.m$^{1/2}$, respectively. For EP+SS containing a 3.5 wt.% of ethanol disulfide, the impact strength and K_{IC} are satisfied a maximum value reaching about 857.8 J/m^2 and 0.409 MPa.m$^{1/2}$ that are 91% and 75% higher than that of neat epoxy, respectively.

From the above results, the plasticizing effect of adding ethanol disulfide to epoxy resin is clear. As mentioned in paragraph regarding the results of DSC test, adding ethanol disulfide to the epoxy leads to a decrease in T_g values. This means that the structure becomes more flexible. Ethanol disulfide has no steric hindrance in the epoxy structure because it doesn’t have aromatic or bulk groups. The material becomes less brittle as it softens, making it less susceptible to flaws or defects. The improved ductility is probably caused by the crack tip reducing before the crack propagates so this enhances the fracture strength and toughness of epoxy modified by ethanol disulfide adding. Additionally, disulfide bonds (S-S) undergoes reversible cleavage and reformation processes under mechanical shear leading to dynamic flexible structure [13,20].

Furthermore, SEM microscopic photo (figure 8) study approves the plasticising effect of adding ethanol disulfde on the mechanical behaviour of EP+SS system.

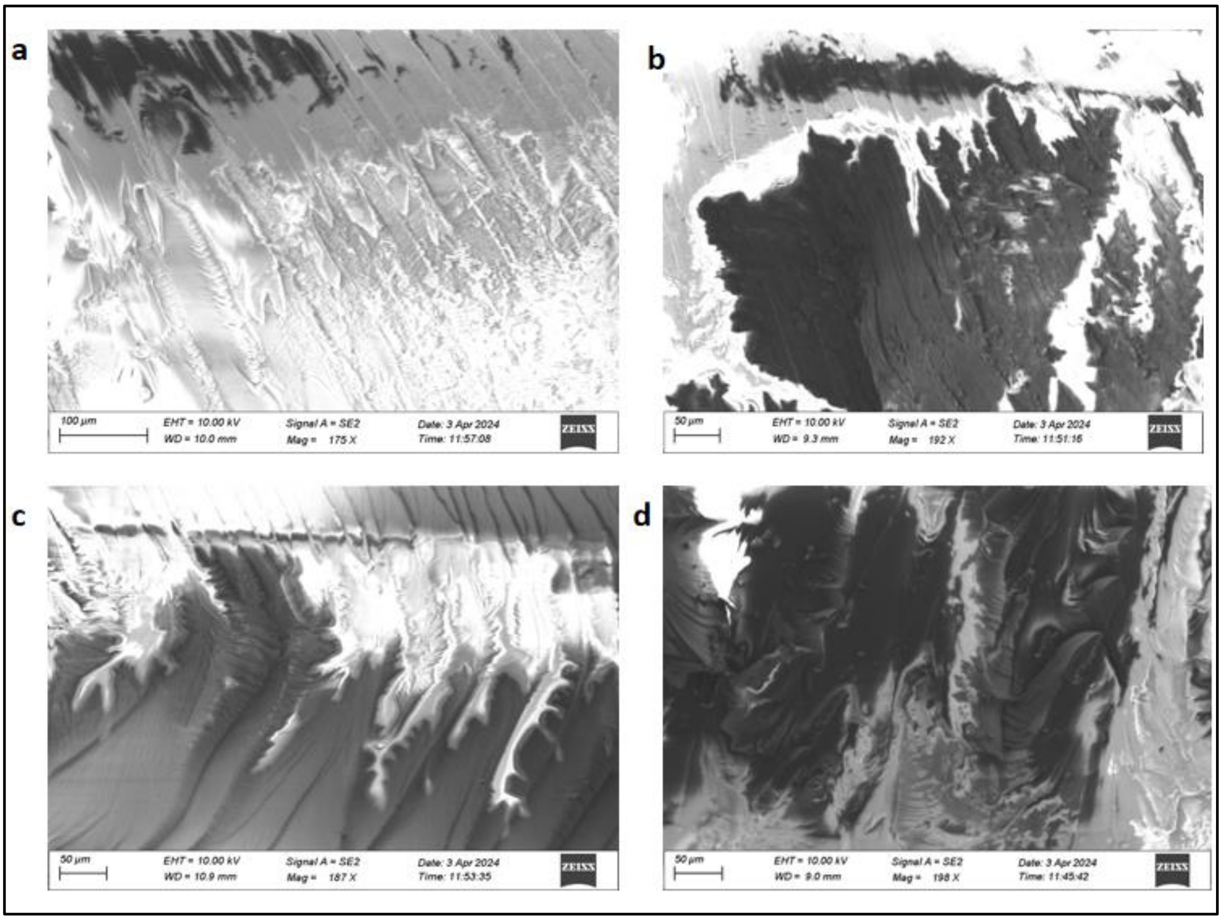


Figure 8. Micrographs from SEM of fracture surface of tensile specimens of: a) neat epoxy, b) 0.5%, c) 1.5%, d) 2.5% EP+SS

3.4. Pull-Off Adhesion Strength

The effect of adding ethanol disulfide compound, at various weight percentages, on the adhesion strength between epoxy coating and steel substrate was estimated by pull-off test. The results are summarised in Table 2 and Figure 9.

The wettability between epoxy coating layer and steel surface was evaluated basing on the values of free surface energy (SFE), contact angle (CA) and work of adhesion from the test of CA. From Figures 10 and 11 and Table 3, it is clear that CA values decrease, but the work of adhesion increases leading to enhanced wettability.

Table 2. the summarised results from pull-off test for neat epoxy and the modified epoxy coatings

Ethanol disulfide content (wt.%)	Adhesion strength (MPa)	Improvement%
0	3.3	-
0.5	8.3	152
1.5	7.66	133
2.5	7.44	127
3.5	6.16	88

Table 3. the value of CA, surface free energy (SFE) and work adhesion (WA) from contact angle test

SS,%	CA,(º)	SFE, (mJ/m^2)	WA,(mJ/m^2)^2
0	47.7	55	121.6
0.5	54.1	51.34	115.4
1.5	39.7	59.45	128.66
2.5	45.9	56.06	123.3
3.5	39.6	59.54	128.7

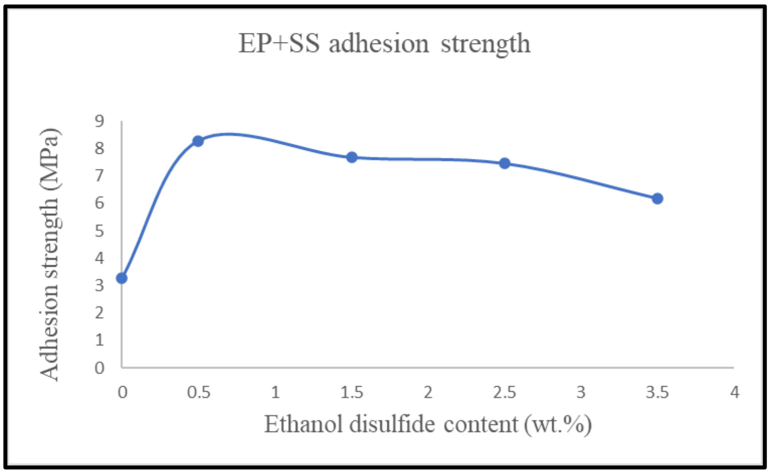


Figure 9. The graphical representation illustrates the correlation between the adhesive strength and the concentration of ethanol disulfide within the epoxy-based protective coating

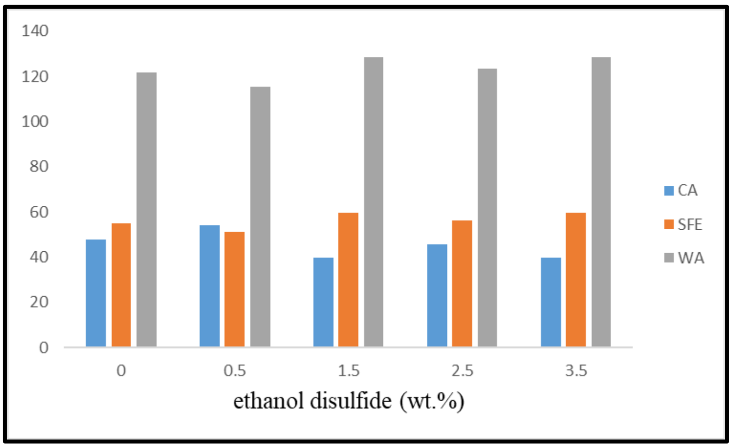
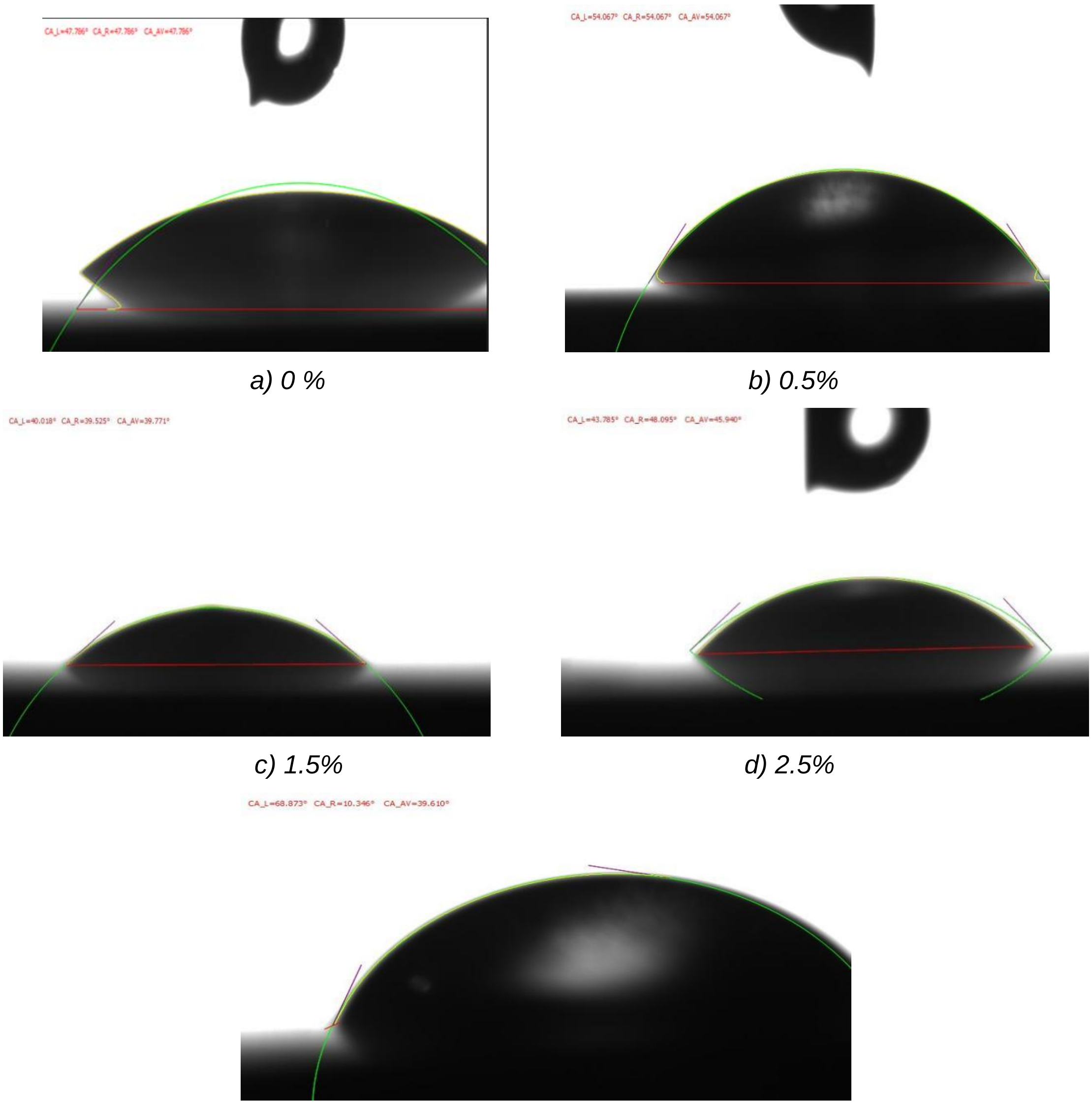


Figure 10. A chart represents the values of CA, surface free energy (SFE) and adhesion work from contact angle test according to content of ethanol disulfide within epoxy coating

From the obtained results, it is clear that an improvement of adhesion strength of epoxy coating is satisfied by incorporating ethanol disulfide into epoxy resin reaching a superior value. Adhesion failure mode, as shown in Figures 12 and 13, is glue-failure where failure occurs at glue-coating interface, at the same time there is no adhesion failure at coating-substrate interface. Epoxy resins inherently generate strong covalent bonds due to its hydroxyl groups [21]. The epoxy formulations containing a compound containing disulfide bonds show enhancedand superior adhesion to the metal surface due to the disulfide bonds which may experience reversible cleavage and reformation during the epoxy curing process. As a result, more covalent connections can be formed by the disulfide groups across the coating-substrate interface.



a) 0 % *b) 0.5%*

c) 1.5% *d) 2.5%*

e) 3.5%

Figure11. measurements of contact angle between the modified epoxy micro-droplet and steel surface

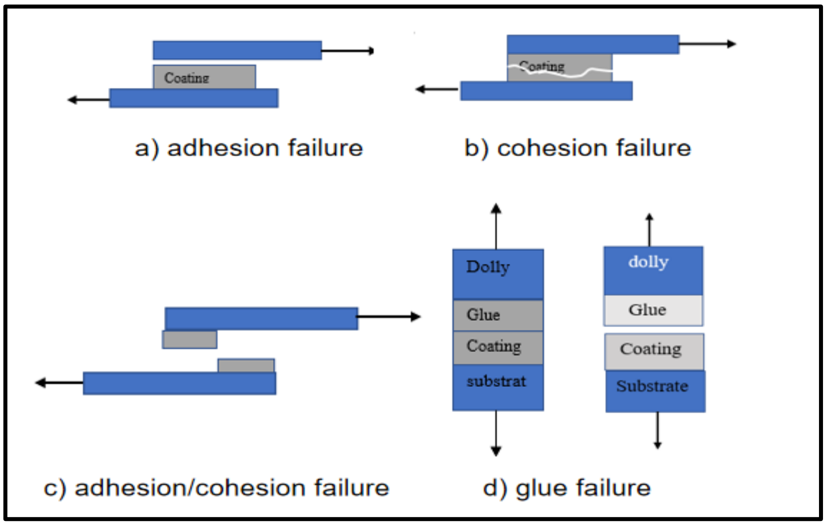


Figure 12. Diagram illustrates failure mode of coating

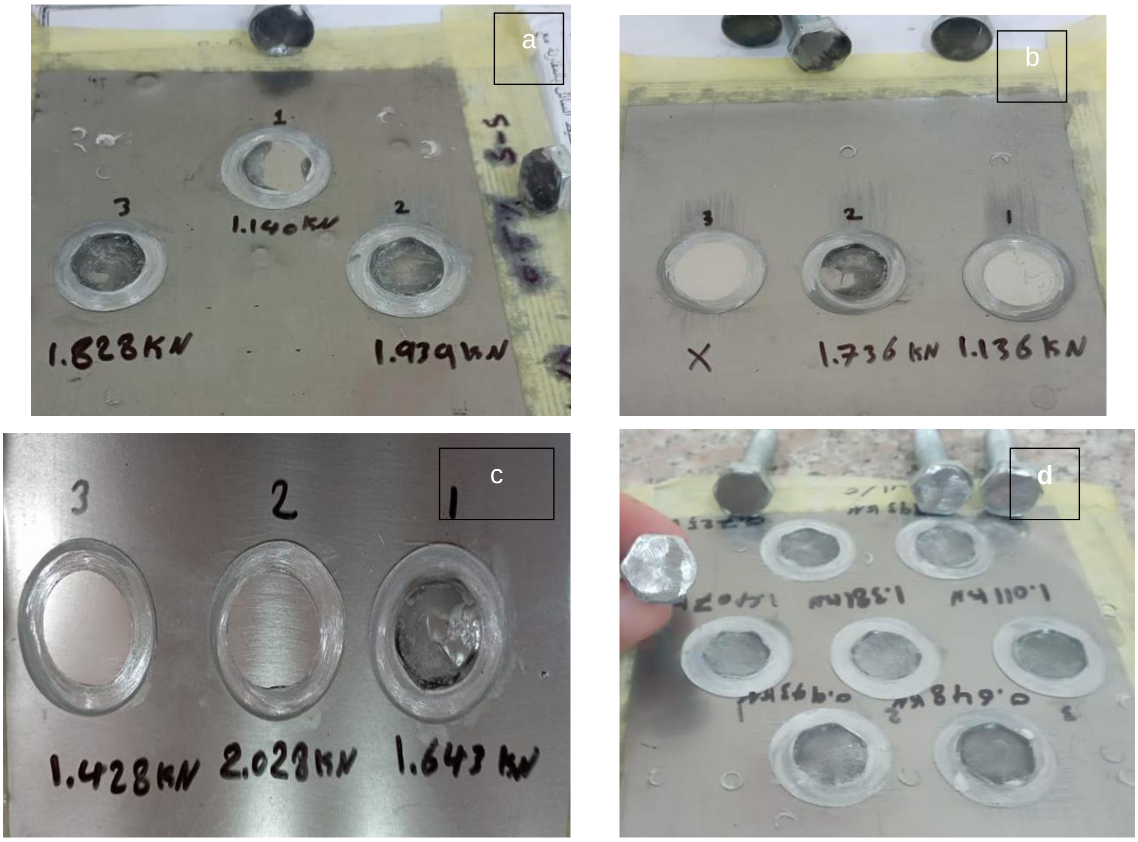


Figure13. photographic pictures for pull-off test specimens: a) 0.5%, b) 1.5%, 2.5% and 3.5% ethanol disulfide containing epoxy coatings

3.5. Wear Properties

Coefficient of friction (COF), wear rate, and plasticity index for neat EP and disulfide containing epoxy are planned in Figure 14 and presented in Table 4. Comparison to neat epoxy, the coefficient of friction of disulfide containing epoxy (EP+SS) highly decreases reaching about 89% when ethanol disulfide content increased up to 2.5 wt.%. Concurrently, as the percentage of ethanol disulphide increases, the rate of wear reduces. The wear rate decreased by 76% compared to the wear rate of pure epoxy. This means a significant improvement in the wear resistance of the epoxy as a result of adding ethanol disulfideto it.

Table 4. The data pertains to the wear rate, coefficient of friction, and plasticity index for the EP+SS coatings

Sample	Wear rate	Improvement%	Coefficient of friction	Improvement%	Plasticity index
0	0.037	-	0.56	-	4.519
0.5	0.01	62	0.54	4	3.859
1.5	0.014	73	0.27	52	2.916
2.5	0.01	76	0.06	89	3.578
3.5	0.009	76	0.12	79	4.177

Because the contacting surfaces' asperities are being removed, there is a noticeable rise in the coefficient of friction during the wear process' early stages. As test progresses, wear track is formed so decreasing COF. We note that the plasticity index (E/H) of EP+SS is lower than that for neat epoxy, and as previously mentioned in the study of the effect of adding ethanol disulfide to epoxy on mechanical properties, the effect of ethanol disulfide as a plasticizer increases the flexibility and toughness of the epoxy structure, thus the resistance to the growth of micro-cracks increases. This enhances material resistance to removal from contacting surfaces. To support this interpretation, we note from SEM microscopic graphs of wear truck in figure 15 that wear truck is blurred and invisible compared to that for neat epoxy. It is also believed that a continuous thin lubricating film forms between the rubbing surfaces, isolating them from each other and reducing direct contact between the surfaces, thus reducing the friction coefficient and wear rate.

It is believed that the disulfide bonds absorb the heat resulting from friction because they are dynamic bonds that are affected by heat, so these bonds cleavage and reorganize themself, thus enhancing the cohesion and integrity of the structure resulting in enhancing resistance for material removal at contact area.

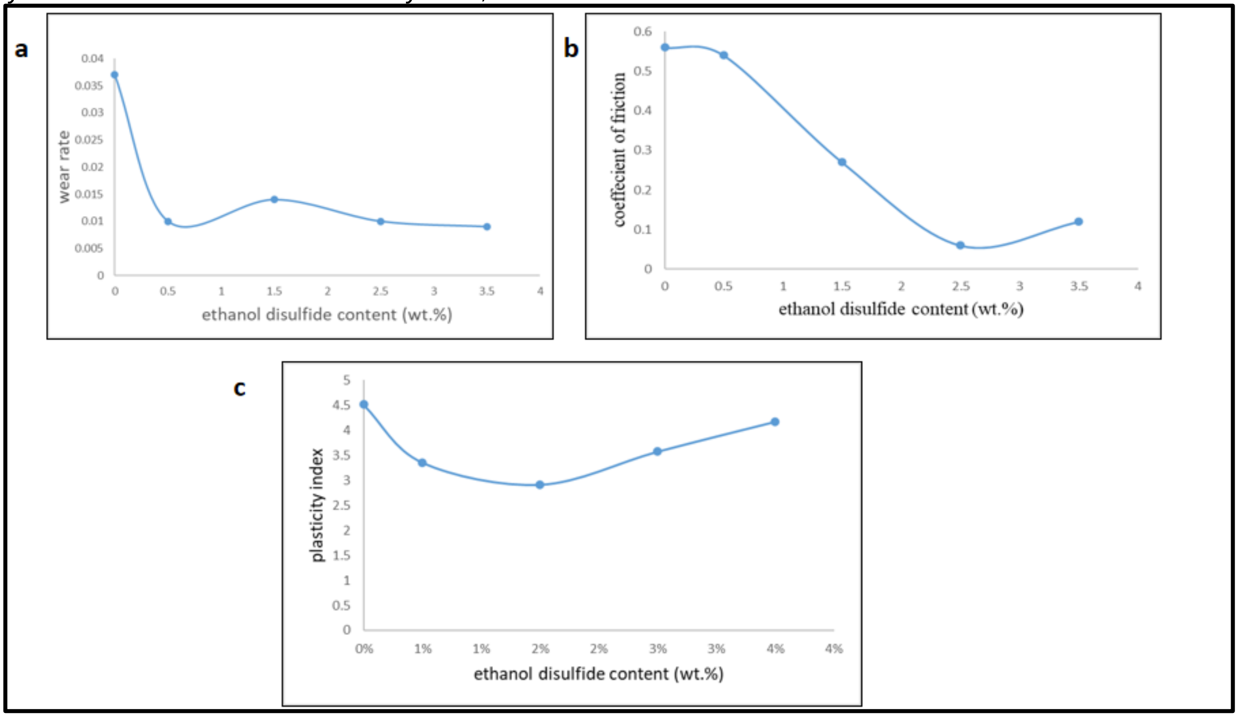
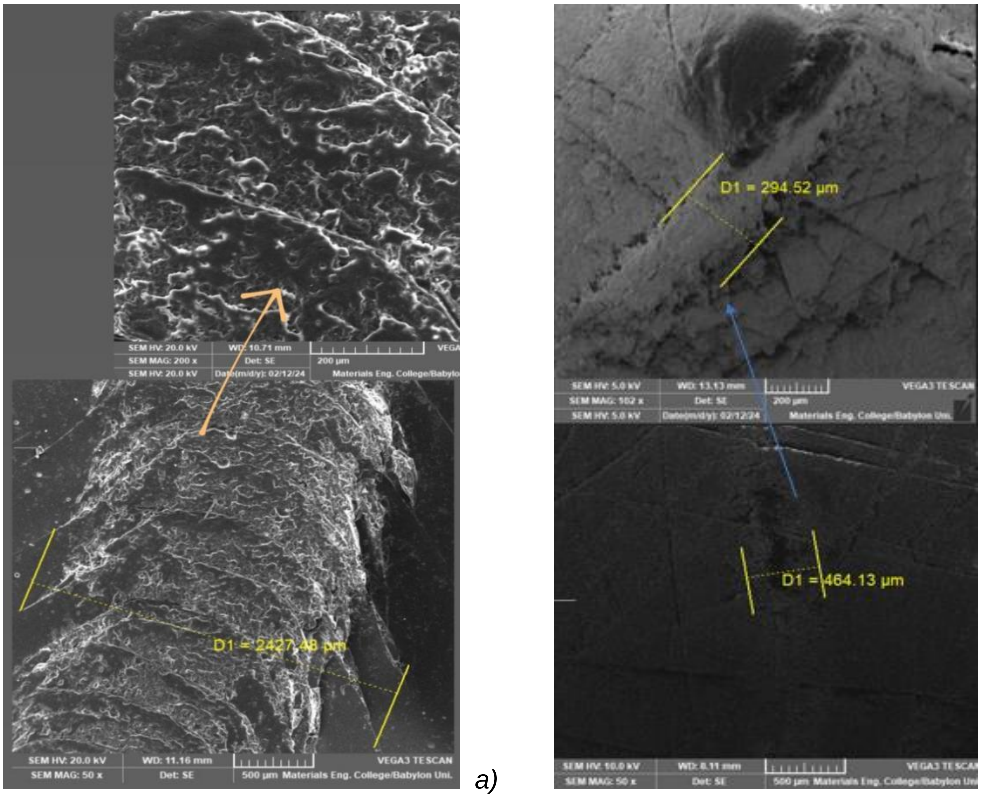


Figure 14. the changes of (a) Coefficient of friction (COF), (b) rate of wear, and (c) plasticity index as a function of ethanol disulfide content in epoxy resin



a) *b)*

Figure 15. SEM micrographs of wear track of: a) neat and b) EP+SS coatings

4. CONCLUSIONS

Adding ethanol disulfide to epoxy resin has significant effects on epoxy properties. DSC analysing results show that a high regression of T_g values of EP+SS compared to neat epoxy.The tensile strength of epoxy decreases by about 26% whereas percentage elongation reaches to 22% at 3.5 wt.% of ethanol disulfide adding and the impact strength and K_{IC} are satisfied at a maximum value reaching about 857.8 J/m^2 and 0.409 $MPa.m^{1/2}$ that are 91% and 75% higher than that of neat epoxy, respectively. Additionally, hardness decreases by about 45%. This indicates improved epoxy toughness and reducingbrittleness with increasing the percentage of the additive. Adding ethanol disulfide to epoxy enhanced the modified epoxy's wear resistance of the modified epoxy, where the friction coefficient wasreduced by 89% and wear ratereduced by 76% for 2.5 wt.% of ethanol disulfide adding. Pull-off strength highly increased and glue-failure mode occurred. Finally, A tough superior adhesive epoxy coating layer was synthesised by incorporation of the ethanol disulfide compound. Using ethanol disulfide for improving the adhesion, wear and mechanical properties of the epoxy coating represents an excellent alternative compound compared to the very expensive amino phenyl disulfide compound.

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IZVOD

DISULFIDNE VEZE MODIFIKOVANE EPOKSIDNE SMOLE: MEHANIČKA, ADHEZIJA I SVOJSTVA HABANJA

Epoksid zauzima važno mesto u mnogim inženjerskim primenama, pa je neophodno poboljšati njegova svojstva kao što su čvrstoća prijanjanja, otpornost na habanje i žilavost. U ovoj studiji, epoksid je modifikovan ugradnjom disulfidnih veza. Sloj prevlake je pripremljen dodavanjem etanol disulfideto epoksidne smole u različitim težinskim procentima: 0,5, 1,5, 2,5 i 3,5 tež.%. Infracrvena spektroskopija sa Furijeovom transformacijom je korišćena za istraživanje bilo kakve hemijske interakcije. Analiza diferencijalne skenirajuće kolometrije (DSC) pruža vredne informacije o termičkom ponašanju pripremljenog epoksidnog premaza. Ispitivana je zatezna, tvrdoća, udarna žilavost, žilavost loma i svojstva adhezije. Ponašanje pri habanju je ispitano pomoću pin-on-disc uređaja. Rezultati pokazuju da epoksid koji sadrži disulfidne veze (EP+SS) nudi odličnu otpornost na udar sa dobrom otpornošću na lom u poređenju sa čistim epoksidom. Pored toga, rezultati ispitivanja kontaktnog ugla pokazuju poboljšanje vlaženja između modifikovanog sloja epoksidnog premaza i čelične podloge. Čvrstoća adhezije epoksidnog sloja je poboljšana ugradnjom etanol disulfida u epoksidnu smolu koja dostiže superiornu vrednost. U poređenju sa čistim epoksidom, koeficijent trenja (EP+SS) je veoma smanjen i dostigao je oko 89%, a stopa habanja je smanjena za 76% kako se povećava procenat dodatog etanol disulfida.

Čvrsti superiorni adhezivni sloj epoksidnog premaza sintetizovan je ugradnjom jedinjenja etanol disulfida u epoksidnu smolu.

Ključne reči: *disulfid, epoksid, habanje, adhezija, dinamičke veze.*

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