

Studies on Acrylonitrile Butadiene Styrene (ABS) and Electroplating on ABS

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ABSTRACT: The introduction of newly developed concept of Electroplating on ACRYLONITRILE BUTADIENE STYRENE (ABS) co-polymer. ABS is an engineering plastic that has butadiene part uniformly distributed over the Acrylonitrile styrene matrix. Though it possess toughness, good dimensional stability, easy processing ability, chemical resistance and cheapness, the main problem is its non conductive nature, so etching is done on it to make conductive. Plating on ABS can serve to enhance the strength and structural integrity as well as to improve durability and thermal resistance resulting in metallic properties on ABS material. ABS is described as the most suitable candidate for plating because it is possible to deposit an adherent metal coating on it by only the use of chemical pretreatment process and without the use of any mechanical abrasion. This presentation aims to review the history of ABS, processes and mechanisms of plating, and studies of plating on ABS involving mainly eco friendly methods of plating.

KEYWORDS: Electroplating, structural integrity, Etching, Non conducting, toughness, dimensional stability, chemical resistance, Mechanical strength, Eco friendly.

I. INTRODUCTION

Plastics are a type of synthetic, semi synthetic or artificial polymers that are capable of being transformed or cast or extruded into various shapes and films. Characteristically, plastics are organic polymers with high molecular mass containing other substances also. Though versatile, plastics cannot be matched with the metal's intrinsic quality of giving a bright lustrous finish. This was considered as a drawback for the automobile industries in the early 1960s, these industries wanted some substitution for metals which were used in majority and hence thought plastics had the potential to replace metals. In early stages, trim components were polished in bright electroplated nickel/chromium, generally known, as 'chrome plating', which offered a high quality lustrous finish. In order to substitute metals with plastics, some method had to be devised for giving a metal like appearance and protection as the metal articles. As a result, the automobile industries started exploring a number of unconventional methods for providing the desired surface finishing like metal articles. But, it was almost immediately realized that substitution for electroplated (EP) nickel/chromium was difficult as the coating not only enhanced the aesthetic view of materials but also enhanced resistance to corrosion and abrasion. Later, in the mid 1960s, procedure for plating Acrylonitrile Butadiene Styrene (ABS) co-polymer was developed. For plating ABS chromic acid based etching solutions were developed. The etching solution actually removes the butadiene phase from ABS to offer a micro-etched bonding site for subsequent deposition of conductive layer. This development happened when innovative trials were being carried out on electroless (copper and Nickel) technologies. The improvements in the etching technique and the development in the electroless plating procedures gave a concrete path for plastics to have a conductive base for subsequent electro deposition process. The base layer also had good bonding with the electrodeposited layers.

II. RESEARCH OBJECTIVE

Specific aim of the project is to develop the metalizing technology suitable for the surface integrity enhancement of IM thermoplastic parts to enable their direct application in developing functional prototypes for real world problems. Technical scope of the proposed project includes studies on surface preparation / surface activation of ABS, electroless and electro deposition of metallic layers, strength characterization of metalized IM parts. The

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proposed research is interdisciplinary in nature as it demands synergistic application of the concepts of material science, mechanical engineering and chemical engineering, for fulfilling the projected research goals.

III. RESEARCH METHODOLOGY

Following tasks are undertaken to help reach the goal of eventually improving the mechanical properties of parts produced by using IM and by using IM parts for functional prototype development, namely:

- Preparation of test coupons through Injection Molding.
- Surface preparation studies on IM specimens through both chemical etching and mechanical means (scoring). Studies on the impact of surface morphology and roughening effect over adhesion strength.
- Setting up laboratory level process line for electrolytic and electroless deposition of metal layers over IM substrates or modules. This activity involves the following steps:
 - Design of the process lines. Fabrication / procurement of plating system modules (chemical etching, rinsing, surface activation, electroless and electrolytic plating modules)
 - Plating trials and optimization of plating parameters (current density, additive concentration, solution level, macro-throwing power capabilities, etc. are among the important parameters)
- Evaluation of mechanical, chemical and physical properties such as tensile strength, flexural strength, impact resistance, hardness, surface integrity, etc. of the prepared samples.

IV. RESULTS AND DISCUSSIONS

MECHANICAL PROPERTY CHARACTERIZATION OF POLY ACRYLONITRILE-BUTADIENE-STYRENE (ABS) IN NON-PLATED AND PLATED CONDITIONS.

To start with the preliminary investigations, ABS samples were fabricated by a injection molding machine and subjected to mechanical tests namely tensile, compression and flexure, adopting standard ASTM test procedures. Table 4.1 was prepared with reference. Table 4.1 presents a comparative statement of the supplier's (Jayalaxhmi Polymers) product data and the results of the mechanical test.

Mechanical Properties	ASTM Standards	ABS (Supplier Data)	ABS(Test data)
Tensile Strength (MPa)	D638	31	30.4
Elastic Modulus (MPa)	D638	2208 - 2622	2536.6
Compressive strength (MPa)	D695	60	59.5
Flexural Strength (MPa) at yield or break	D790	32-35	35
Flexural Modulus (MPa)	D790	2346 - 2691	2640

Table 4.1: Properties of Normal ABS Samples

Mechanical Properties	ASTM Standards	EP-ABS		
		15 μm	35 μm	55 μm
Tensile Strength (MPa)	D638	33.48	34.11	35.63
Elastic Modulus (MPa)	D638	2644	2699	2752
Compressive strength (MPa)	D695	61.16	95.05	103.82
Flexural Strength (MPa) at yield or break	D790	45.466	50.920	57.719
Flexural Modulus (MPa)	D790	2701	5970	6883

Table 4.2: Properties of Electroplated ABS Samples

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The ABS samples were injection molded as per the ASTM standards. Mechanical properties (tensile and compression), as discussed in the Tables 4.1 and 4.2 are measured using a computer interfaced Universal Testing Machine (model: TUE-C-400) of 40 T capacity. Tensile strength is measured as per ASTM D638 (Type I). The sample dimensions were as per fig. (a) with an overall length of 165mm, gauge width of 13mm and thickness of 7 mm. The speed of testing is chosen to be 5 mm/min as specified in the standard. Modulus determination is also made at the selected speed. Compression strength is measured as per ASTM D695 standard testing procedure. The sample dimensions were as per the fig. (b), the measured dimensions were of 25.4 mm x 12.7 mm (width) x 12.7 mm (thickness). The speed of testing is chosen to be 1.3 ± 0.3 mm / minute as specified in the standard. Flexural strength / modulus were measured following ASTM D790 standard. The sample dimensions were as per the fig. (c), the measured dimensions were of 127 mm (length) x 12.7 mm (width) x 6.4 mm (thickness). The speed of testing is set at 2.6 mm/min using the equation ($R = ZL^2/6d$, mm / min where Z= 0.01mm/mm/min, L= support span, 100 mm, d = depth of beam, 6.4 mm) specified in standard. Each value presented is an average of five measurements made from the five



Figure (a): Tensile Test Sample as per ASTM D638 (Type I)

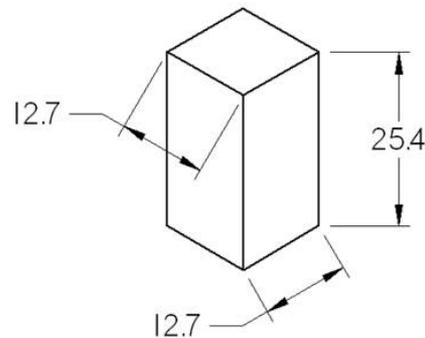


Figure (b): Compression and Ash Content Test Sample

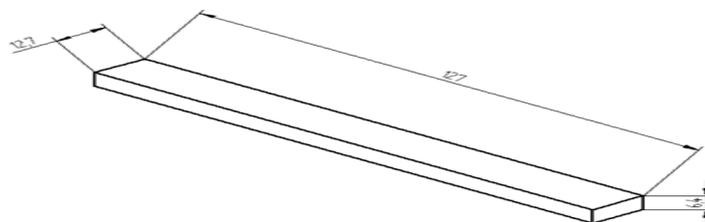


Figure (c): Dimensions of Flexure Test Sample as per ASTM D790

Fig. 4.1 represents the stress vs. strain relationship of ABS sample subjected to the tensile test under plated and non-plated conditions. The tensile strength of ABS is more or less the same value as specified by the supplier. The modulus of ABS is within the specified range as seen from Table 4.1. The maximum tensile stress and modulus values of ABS is 30.4 MPa, and 2536.6 MPa, respectively, when compared to a maximum stress and modulus of 31 MPa, 2208 – 2622 MPa, respectively, as indicated by the supplier's data. The ABS tested samples indicate a brittle mode of fracture. The observed failure of ABS samples indicates reduced matrix elongation without the neck formation.

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Table 4.2 lists the tensile strength of ABS samples in electroplated conditions. It is seen that 15, 35, 55 μm samples have shown enhanced strength due to fact that they are hybrid composites after electroplating. Similar observations have been made by Z Zou et al. They say that electroplating creates layered composites which give the strength.

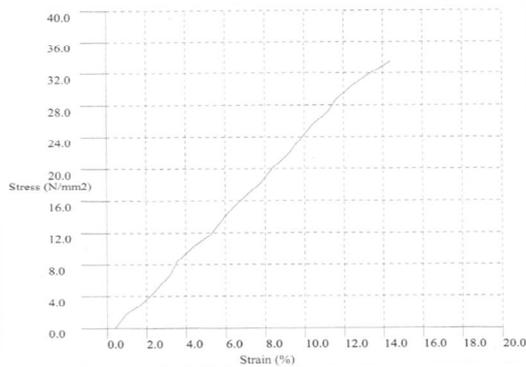


Figure 4.1: Tensile test: stress vs. Strain diagram Of Normal-ABS Samples

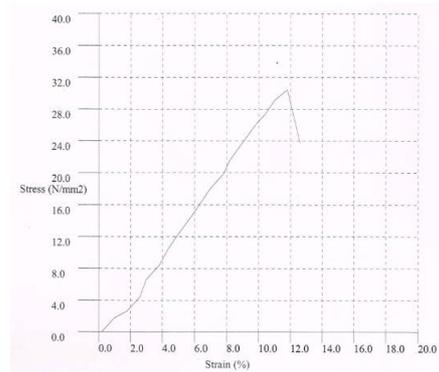


Figure 4.2: Tensile test: Stress vs. Strain diagram of Electroplated (EP) -ABS Samples (15 μ)

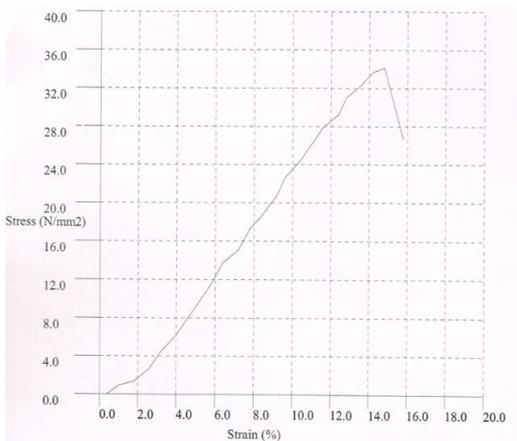


Figure 4.3: Tensile test: Stress vs. Strain of EP-ABS Samples (35 μ)

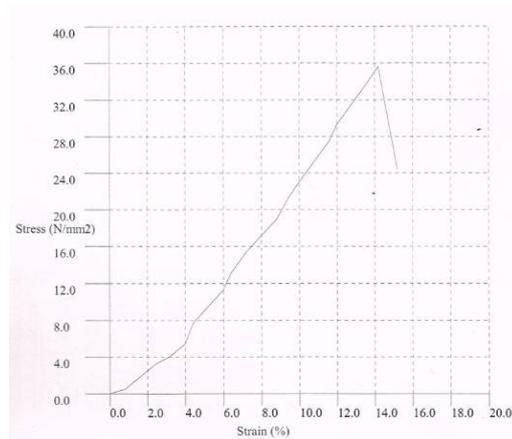


Figure 4.4: Tensile test: Stress vs. Strain diagram of EP-ABS Samples (55 μm)

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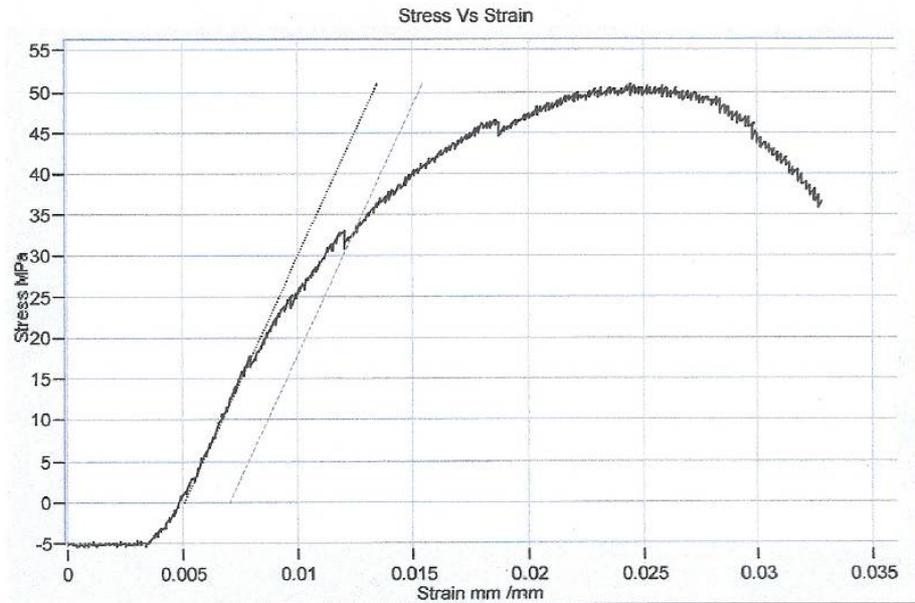


Figure 4.7: Flexure test: Stress vs. Strain diagram of EP-ABS samples. (35 μm) (conducted at Cosmic Labs Bangalore)

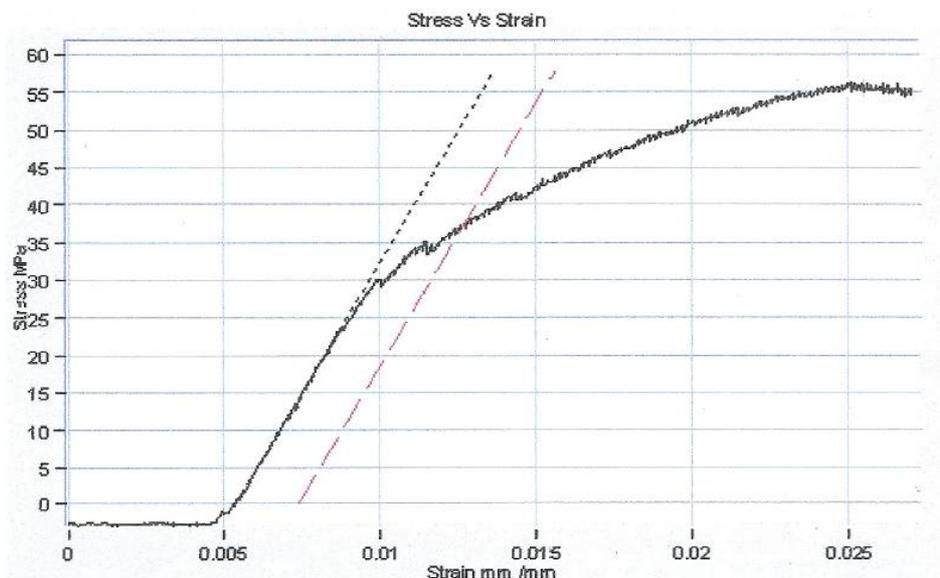


Figure 4.8: Flexure test: Stress vs. Strain diagram of EP-ABS samples. (55 μm) (conducted at Cosmic Labs Bangalore)

Figs. 4.5 – 4.8 represent a typical stress vs. strain relationship of ABS sample subjected to 3 point flexural loading. The maximum flexural stress and modulus values attained by the ABS sample in plated and non-plated conditions have been briefed in Table 4.1 and 4.2. It is understood that electroplated samples in flexural conditions have shown a tremendous improvement in strength. The modulus values have also increased. This indicates electroplated samples exhibit better properties over tensile samples and thus could be used in flexure related

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applications. The electroplated copper, nickel and chrome layers undergo thorough expansion during flexing and thus increases the strength and modulus values. According to Z. Zhou et al. [50], the reason for the improvement may also be due to the enhanced adhesive interface for the flexural test than the tensile test and for these flexural tests, the moment of Inertia is important. Therefore, it is not only important to note that not only the adhesive strength but also the geometrical factors play a very significant role in designing of EP components from the strength point of view.

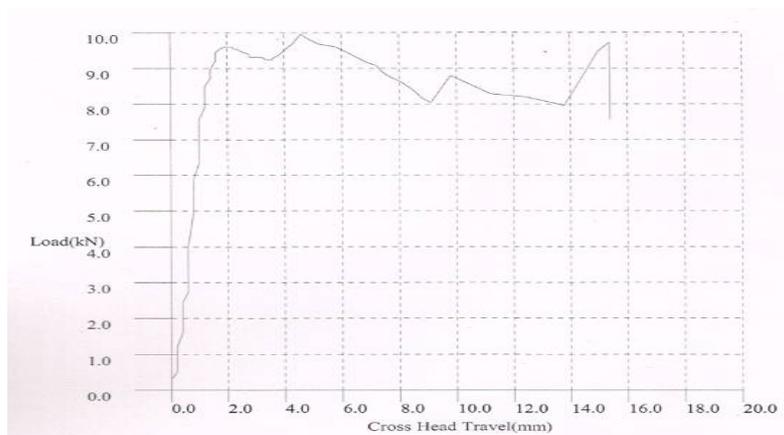


Figure 4.9: Compression test: Stress vs. Strain diagram of ABS samples.

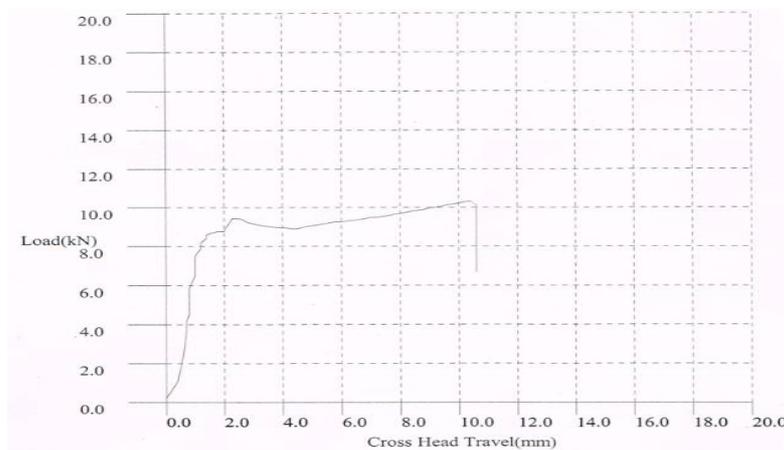


Figure 4.10: Compression test: Load vs. Displacement curve of EP-ABS samples. (15µm)

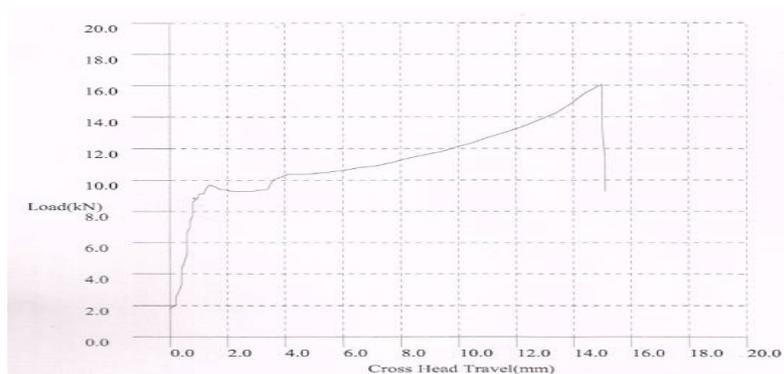


Figure 4.11: Compression test: Load vs. Displacement curve of EP-ABS samples. (35µm)

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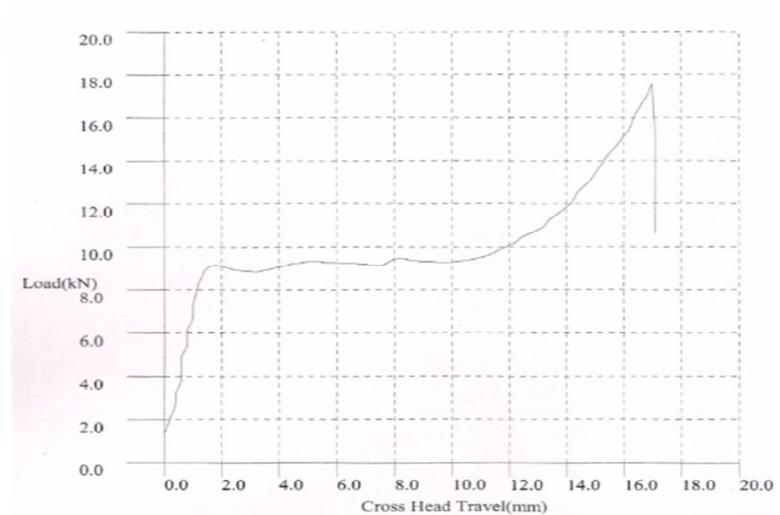


Figure 4.12: Compression test: Load vs. Displacement curve of EP-ABS samples. (55µm)

Figs. 4.9 – 4.12 shows the load-displacement curves of non-plated and plated ABS samples. The EP samples have shown a considerable improvement in strength over the normal samples. The coated compressed samples initially did show the failure of coating but later on the samples did not show any mode of failure or fracture and just underwent compression. The presence of electroplating layer results in higher moisture resistance resulting in increased strength also the enhancement in the strength may also be attributed to the better surface bonding at the metal / base interface.

The improvement in tensile, flexure and compression properties certainly ensures the structural stability of the composites.

HARDNESS

Hardness is defined as the resistance of a material towards penetration / indentation, scratching, cutting, tearing, etc. Hardness has no perfect definition, yet it is considered to be an important property to be tested for materials specification. Fig. 4.13 shows that the hardness of EP-ABS samples are much superior over normal ABS samples (non-plated).

It is generally known that, when fibers or other types of reinforcement are incorporated into a matrix, the presence of the reinforcement can enhance the properties of the fabricated composites. Similarly, when reinforcements are made externally there will be enhancement in the hardness values of the samples and is proved in this study.

From the Table 4.3, it is observed that samples (15µm, 35 µm, 55 µm) subjected to electroplating exhibit an increase in hardness by 6%, 12% and 20% respectively. J N Prakash, in his studies on fiber metal laminates, reports that hardness of the samples do not increase to a greater extent in case of fibre metal laminates due to the following reasons: (i) lower stress transfer rate under loading (ii) to weaker metal / matrix interface adhesion. In the present research, the EP samples behave like bonded laminates and therefore the reasons as quoted by J. N. Prakash [55], may hold good for the EP samples.

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Condition of Samples	Material - ABS			
	Non-plated	15µm	35µm	55µm
Normal	97.8	--	--	--
Electroplated	--	104	110	118

Rockwell hardness, HRR

Table 4.3: Hardness Values of ABS samples in non-plated and electroplated conditions

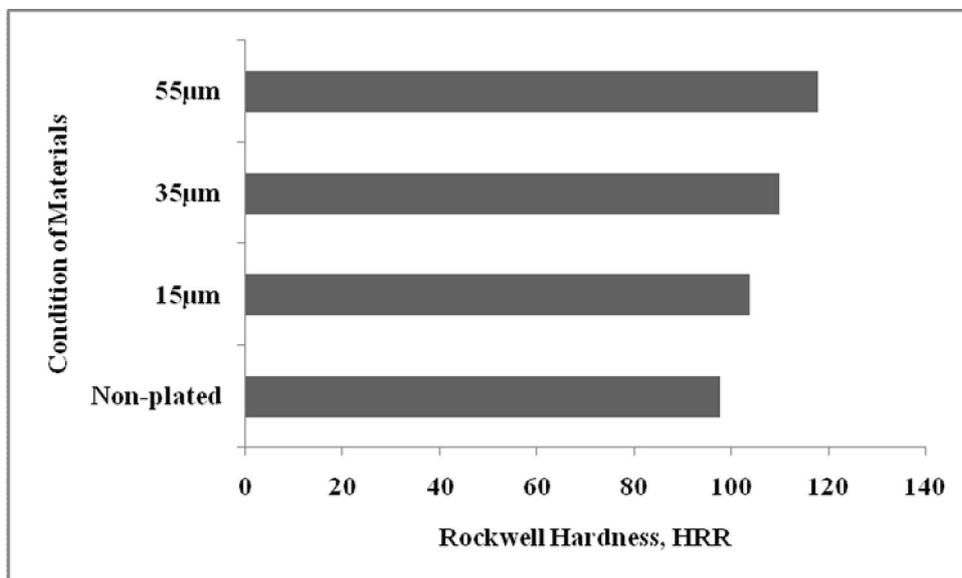


Figure 4.13: Hardness Test Values of ABS samples in non-plated and plated conditions

WEAR TESTS

Tribological performance of polymers and its composites are generally sensitive to operating and test conditions. These conditions make it difficult to understand the wear performance of PMC's. Some of the factors like pre and post treatment operations on polymers, environmental and operational conditions etc., have an effect on wear and friction properties.

Various researchers have pointed out that PMCs cannot offer opposition to all the different modes of wear [56, 60, 62, 63]. Tribological behavior of plastics can be enhanced by the inclusion of fillers [60, 62]. In the present investigation the tribological performance of ABS under normal / dry sliding and EP conditions are compared.

Sliding Velocity, m/s	Coeff. of Wear	Wear Loss, gm	Condition of samples
2.5	1.81E-08	0.001	55µm
5	3.63E-08	0.002	
7.5	4.62E-08	0.0025	
2.5	7.43E-08	0.004	35µm
5	9.16E-08	0.005	

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7.5	1.10E-07	0.006	15µm
2.5	9.70E-08	0.007	
5	1.17E-07	0.008	
7.5	1.70E-07	0.0085	
2.5	1.31E-07	0.009	Nonplated
5	1.66E-07	0.0095	
7.5	1.33E-07	0.01	

Table 4.4: Wear resistance Test Values of ABS samples in non-plated and electroplated conditions

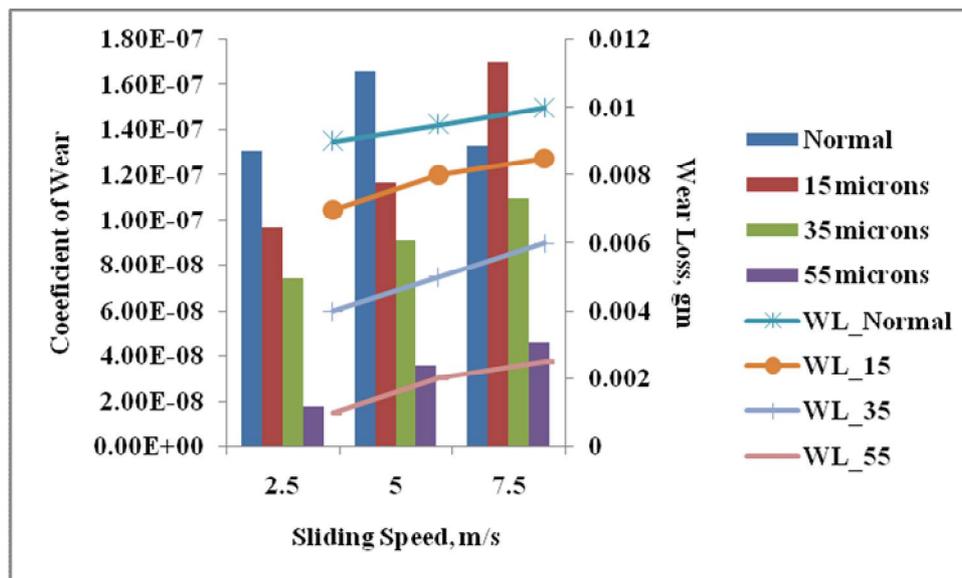


Figure 4.14: Wear Test Values of ABS samples in non-plated and plated conditions

ABS samples subjected to wear studies under the dry and electroplated conditions are as shown in the Table 4.4. The Table gives the details of changes in frictional coefficient and weight loss in grams of ABS samples subjected to dry sliding wear. The wear samples were been subjected to normal load of 1Kg and sliding velocities from 2.5 m/s to 7.5 m/s for a constant sliding distance of 1000 meters.

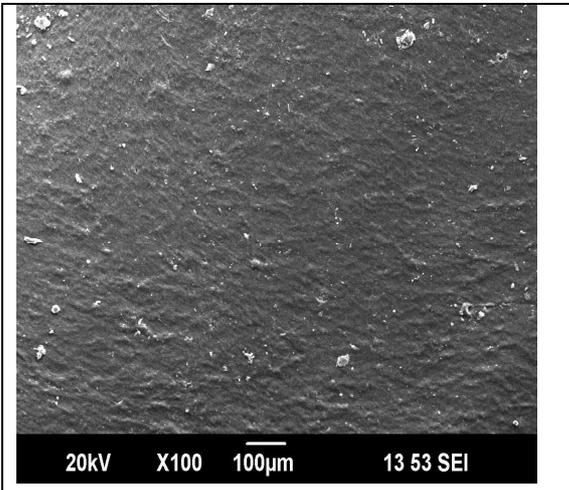
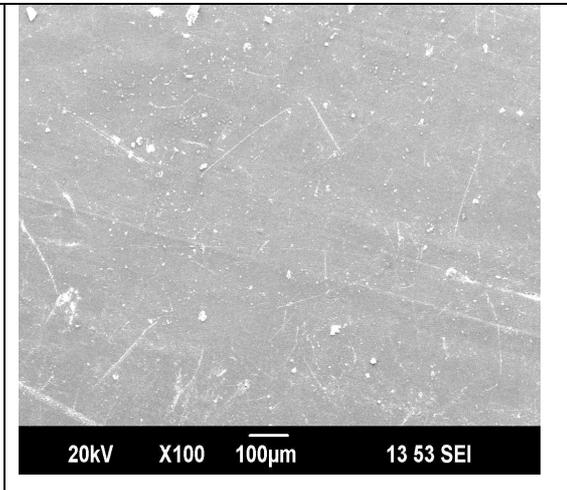
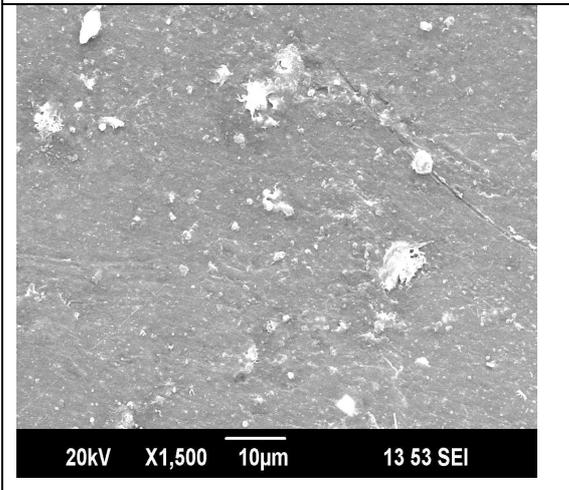
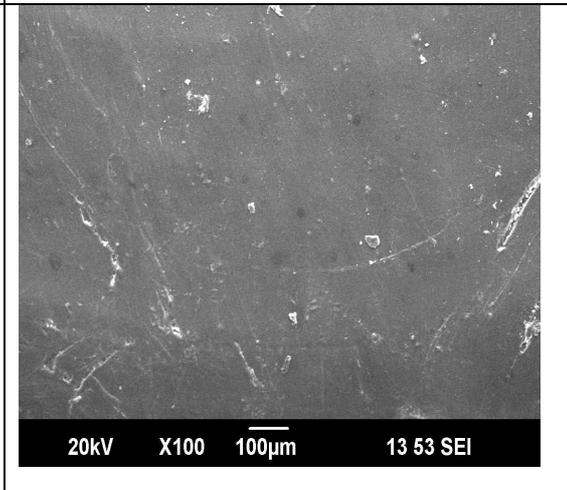
Fig. 4.14 shows the ABS normal and electroplated samples subjected to different rubbing velocities and constant load conditions. The results indicate that samples show higher friction coefficient and wear loss when rubbing velocity changes from 2.5 m/s to 5 m/s. The behavior observed is different when the velocity changes from 5 m/s to 7.5 m/s that is, reduced friction coefficient and wear loss. This indicates that sliding speeds has an important role on friction and wear in dry conditions [63]. With the increase in sliding velocity from 2.5 m/s to 5 m/s, the frictional heat accompanied with normal load, shear force and frictional thrust decreases the strength of the samples and these factors accelerate the wear rate thus increasing the friction coefficient. The findings are in agreement with the findings of Chowdhury et al. [64], Mimaroglu A [65], Suresha B C [66]. But, when the velocity changes from 5 m/s to 7.5 m/s, the frictional heat developed is so large that it starts to melt the samples. The melting smoothens the surface of ABS sample, which is in contact with rotating disc and further contributes to slipping between sample and disc interface that reduces the friction coefficient and wear loss.

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The SEM's from the fig. 4.15 provides the evidence for the explanation given in this section. Fig. 4.15 (a) shows the SEM of normal ABS sample subjected to rubbing velocity of 2.5 m/s and an applied load of 1 kg. No cracks or scars are observed on these samples. The fig 4.15 (b) shows the presence of scars or pockmarks that are formed due to the change in rubbing velocity from 2.5 m/s to 5 m/s. These are formed when particles of polymer are torn from the surface of the polymer due to the increased speed. The local shear stresses and the frictional heat softens the polymer surface and further tears the polymer surface. The debris or torn particles as observed from fig. 4.15 (c) now plays the role of a third body (abrasives) that causes further wear loss [67]. Fig 4.15 (c) reveals the reduction in number of scars or scratches formed on the samples subjected to a rubbing velocity of 7.5 m/s, which indicate that frictional heat, load and sliding velocity play a major role in bringing down the wear loss and friction coefficient.

	
<p>Figure 4.15 (a): SEM of Normal ABS sample subjected to applied load of 7 kg, sliding velocity of 2.5 m/s and sliding distance of 1000 m.</p>	<p>Figure 4.15 (b): SEM of Normal ABS sample subjected to applied load of 7 kg, sliding velocity of 5 m/s and sliding distance of 1000 m. (at X100 magnification)</p>
	
<p>Figure 4.15 (c): SEM of Normal ABS sample subjected to applied load of 7 kg, sliding velocity of 5 m/s and sliding distance of 1000 m. (at X1500 magnification)</p>	<p>Figure 4.15 (d): SEM of Normal ABS sample subjected to applied load of 7 kg, sliding velocity of 7.5 m/s and sliding distance of 1000 m.</p>

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From the fig. 4.15, it is seen that coefficient of wear and wear loss decreases with increase in electroplating thickness. The wear loss is almost linear with the rise in sliding velocity. It is noted that samples subjected to 7.5 m/s sliding velocity and 1 kg applied load and beyond does not have the necessary resistance to wear. The sample loses the EP layer at this point and the ABS surface gets exposed to the disc and due to which lower wear loss and friction coefficient is observed. The wear loss increases at 2.5 m/s and 1 Kg load and this is due to the high frictional heat that is transferred from copper layer to the core (ABS) before the sample gets completely rid of the EP layer. Also, the rise in COF and wear rate is accelerated by the worn out EP particles that acts as abrasives and increases the wear rate and COF.

Fig. 4.16 shows the SEM image of EP-ABS sample subjected to a normal load of 1 kg and rubbing velocity of 5 m/s. It is observed that the worn surface of ABS under EP condition is characterized by scratching at an angle of approximately 15-30° to the sliding direction. But the SEM of the normal sample subjected to the same condition show a different wear, where lesser debris is found adhering to the normal samples as compared to EP sample. The debris in EP sample is due to the hard chrome and nickel particles that act as abrasives and dig more into the soft ABS surface.

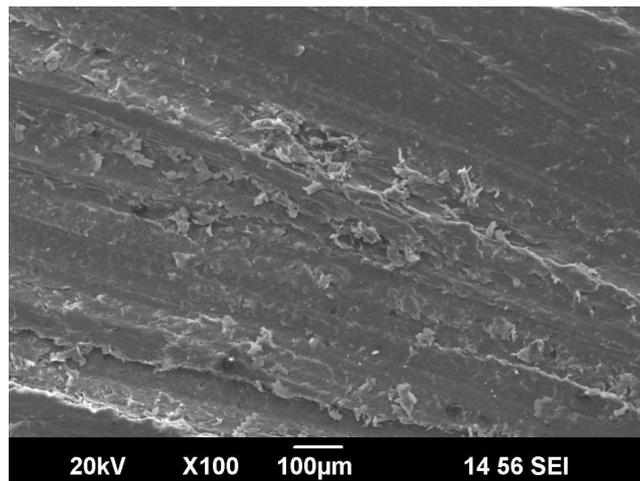


Figure 4.16: SEM of Electroplated ABS sample subjected to applied load of 1 kg, sliding velocity of 5 m/s and sliding distance of 1000 m.

V. CONCLUSIONS

- The **coating characterization studies** conducted on the electroplated samples included tests like, salt spray test, Adhesion evaluation test, Acetic acid test, Coating thickness test., etc.
 - ✓ The test revealed that samples had undergone correct coating / plating methods and did not have any presence of residual stresses. This was observed with acetic acid tests.
 - ✓ The adhesion test revealed that plating had properly adhered with the basic ABS plastic and this could be attributed to the proper surface treatment.
 - ✓ The salt spray test was conducted for a period of 24 hours and the samples (electroplated) did not show any signs of red and white rust on the coated samples.
 - ✓ Coating thickness was also conducted as per IS standards and the results of the tests indicated that samples were coated for a thickness of 15µm, 35µm and 55µm.

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- The mechanical tests like Tensile, Compression, Flexure and Hardness were conducted on samples (Injection Molded) and the results of the tests indicate that.,
 - ✓ IM-EP Compression, Flexural, and Hardness samples exhibited enhanced strength in comparison with non-plated samples. The obvious reasons being the electroplated layers.
 - ✓ It is also evident from the tests that EP samples had shown an improvement in the strength. The strength got enhanced with the increase in the coating thickness. The Tensile-ABS (EP) samples did not show much improvement with electroplating as compared with IM samples.
 - ✓ The drop impact tests conducted also revealed that samples exhibited better resistance to impact load in electroplated conditions.
 - ✓ Wear studies also indicated that electroplating of ABS plastics offered better resistance to wear loss and reduced coefficient of wear.

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