# Characterization of UPR-Steel Slag Composite: Effects of Steel Slag Content and Particle Size

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# DECLARATION

I declare that this thesis entitled "title of the thesis" is the results of my own research except as cited in the references.

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**PENCIRIAN KOMPOSIT UPR-SLAG KELULI: KESAN KANDUNGAN DAN SAIZ ZARAH SANGA KELULI**




## ABSTRAK

Sanga keluli adalah sisa industri yang boleh digunakan dalam resin poliester tak jenuh (UPR) sebagai pengisi. Tujuan kajian ini adalah untuk mencipta komposit UPR-sanga keluli dengan jumlah sanga keluli dan saiz zarah yang berbeza. Sanga keluli dikisar terlebih dahulu selama 40 jam menggunakan pengisaran bola, dan kemudian di mampat-acuan dengan UPR. Pengenalan fasa, kekristalan, dan morfologi sanga keluli terkisar dan komposit UPR-SS telah diperiksa. Sanga keluli terkisar, yang terdiri daripada oksida besi dan silikat, mempengaruhi kekristalan komposit berdasarkan jumlah slag keluli dan saiz zarah. Kajian ini telah dapat menentukan bahawa kedua-dua jumlah sanga keluli dan saiz zarahnya mempunyai kesan ke atas fasa, kumpulan berfungsi dan morfologi komposit UPR-SS. Analisis X-ray diffraction (XRD) mendedahkan bahawa komposit menunjukkan tahap kristalin yang tinggi, dengan komposit yang mengandungi partikel bijih keluli yang mempunyai saiz 125 μm, berbanding dengan 45 μm. Untuk meningkatkan pembentukan kristal dan mengurangkan saiz bijirin dalam matriks UPR, penggunaan partikel bijih keluli kecil berukuran 45 μm digunakan. Selain itu, ia lebih cenderung bahawa komposit dengan 125 μm akan menunjukkan penyerapan yang lebih rendah berbanding komposit dengan 45 μm bahan-bahan keluli. Ini disebabkan oleh fakta bahawa lebar, intensiti, dan kawasan band dalam spektrum FTIR komposit secara langsung bergantung kepada saiz partikel purata komposit. Dalam matriks UPR, penyertaan SS dengan saiz partikel 45 μm membawa kepada penyebaran yang lebih seragam berbanding dengan pita keluli 125 μm, seperti yang ditentukan oleh mikroskop elektron pemindaian (SEM).

**CHARACTERIZATION OF UPR-STEEL SLAG COMPOSITE: EFFECTS OF STEEL SLAG CONTENT AND PARTICLE SIZE**

## ABSTRACT

Steel slag is an industrial waste that can be used in unsaturated polyester resin (UPR) as filler. The aim of this study is to create a UPR-steel slag composite with varying amounts of steel slag and particle sizes. The steel slag was first milled for 40 hours in a ball mill and then compression molded with UPR. The phase identification, crystallinity, and morphology of the as-milled and UPR-SS composites were examined. The as-milled steel slag, primarily composed of iron oxide and silicates, influenced the crystallinity of the composites based on the steel slag loading and particle size. This study determined that both the total amount of steel slag and its particle size have an impact on phase, functional group, and morphology of UPR-SS composites. The X-ray diffraction (XRD) analysis revealed that the composite exhibited a high degree of crystallinity, with composites containing steel slag particles measuring 125 μm in size, as opposed to 45 μm. In order to enhance the formation of crystals and decrease the size of grains in the UPR matrix, the utilization of small steel slag particles measuring 45 μm was employed. Furthermore, it is more likely that the composite with 125 μm will exhibit lower absorption compared to the composite with 45 μm steel slag materials. This is due to the fact that the width, intensity, and area of bands in FTIR spectra of composites are directly dependent on the average particle size of the composite. Within the UPR matrix, the incorporation of SS with particle sizes of 45 μm results in a more uniform distribution compared to the 125 μm steel slag, as determined by scanning electron microscopy (SEM).

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| CaO | Calcium oxide |
| UPR | Unsaturated Polyester Resin |
| MPa | Megapascal |
| XRD | X-Ray Diffraction |
| SEM | Scanning Electron Microscope |
| FTIR | Fourier-Transform Infrared Spectroscopy |
| FeO | Iron oxide |
| rpm | Revolution per minute |

**LIST OF SYMBOLS**

| | |
|---|---|
| µm | Micrometers |
| wt% | Weight percentage |
| $cm^{-1}$ | Reciprocal wavelength |
| ° | Degree celcius |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background of Study

Steel slag is a by-product of the process created from molten steel that is separated from impurities in steel-making furnaces. It is primarily composed of iron and magnesium oxides produced as a result of the oxidation of various elements in the furnace charge, eroded lining materials, and added slagging materials. Steel slag's features are determined by its complex composition and structure, which expands the range of applications for which it can be utilized as low-cost filler, including the manufacturing of fertilizer, cement, concrete aggregate, and aggregate for roads (Yi et al., 2012). In addition, the use of steel slag as filler has shown promising results in significantly enhancing the mechanical properties, thermal and chemical properties of the polymer composites (Babu et al., 2009; Gobetti et al., 2021; Purohit et al., 2019). However, they are mostly utilized as fillers in the epoxy composite. In addition, there are a few studies focusing on the utilization of steel slag as filler in the unsaturated polyester resin (UPR) composite.

The addition of waste inorganic fillers such as steel slag in the polymer matrix may reduce the manufacturing cost. The optimum content and particle size of steel slag leads to a homogenous composite structure. In epoxy composite production, the amount of steel slag affects the tensile strength of the composite. The particle size of the steel slag used can vary from a few microns to several millimeters. Smaller particle sizes can increase the surface area of the slag and improve the adhesion between the steel slag and matrix, resulting in a more homogeneous composition. Finer particles tend to improve workability and increase strength, while coarser particles may reduce the workability and strength of the polymer composite. Moreover, steel slag particles with a maximum size of around 1 mm or less are used for polymer composite (Guzel & Deveci, 2018). Thus, proper testing and evaluation are essential to determine the optimal content and particle size and ensure that the final product meets the required standards and specifications. This study aims to produce the UPR composite with steel slag addition as well as to determine the mechanical properties of the composite. The effect on different amount and particle size of steel slag will be discussed.

## 1.2 Problem Statement

Among the family of thermosetting polymers, polyester resin is the one with better mechanical properties to combined with steel slag (Sathishkumar et al., 2022). The unsaturated polyester resin (UPR) is generally cheaper than other resins and are commonly available. Steel slag is an industrial waste that can be used in UPR. The combination of UPR and steel slag known for its high tensile strength and mechanical properties. Particle size is important factor to consider when using steel slag as filler in polymer composite. If the particles are too large, they may cause problems with workability and output of a material. On the other hand, if the particles are too small, they may not provide enough strength to the material and may lead to segregation and bleeding (Feng & Sun, 2020). So, it is important to carefully evaluate these factors and to ensure that the steel slag is properly processed and blended with other materials to optimize its benefits and minimize any potential problems.

There are several problems arise when using pure UPR without adding steel slag as filler. The pure UPR has a tendency to be brittle, particularly after it has cured. Because of this brittleness, the finished product may be at risk of cracking or breaking when subjected to stress. In most cases, UPR experiences a significant amount of shrinkage while it is curing. This shrinkage can cause the final product to become deformed or distorted, particularly in sections that are larger or thicker than its original dimensions (Abed et al., 2022). When compared to other resin systems such as epoxy or vinyl ester, the heat resistance of pure UPR is relatively low. Because of the possibility that it will become softer or degrade at higher temperatures, its use in high-temperature applications is restricted.

Reinforcements are needed to be used in UPR to minimize the amount of distortion or deformation that occurs in the final product by reducing the shrinkage of UPR during the curing process (Jones, 2017). The dimensional stability of UPR composites can be improved by the addition of reinforcement materials, which has the effect of reducing the potential of the material to deform or change shape in response to changes in load or temperature. Previous reinforcements used in UPR are glass fibers, carbon fibers, aramid and natural fibers. Because glass fibres can be brittle, they may break or crack when under stress. They might also be less suitable for some applications due to their poor resistance to corrosion and fatigue. Carbon fibres can be costly and fragile to abrasion or impact damage. In general, natural fibres are less mechanically strong than synthetic ones, and they can break down in the presence of moisture or UV light.

By conducting this research, it can solve the problems for industries which are in large scale. For industries, the development of UPR composites with steel slag fillers may present new market opportunities. These materials could be used in the transportation, infrastructure, automotive, and building industries which have a need for strong, affordable, lightweight materials. The utilisation of steel slag as a filler in UPR composites is consistent with the principles of the circular economy and sustainable manufacturing practices. It lessens the need for virgin raw materials, protects the environment, and emits the fewest greenhouse gases during the production process of conventional fillers (Abed et al., 2022).

## 1.3 Objectives

The objectives of this research are:

1. To prepare the UPR-steel slag composite at different steel slag content and particle size using compression molding.

2. To evaluate the phase identification, morphology, physical properties of the UPR-steel slag composite at various steel slag content and particle size.

## 1.4 Scope of Study

In this study, the three main elements which are structural, morphology and thermal properties of the incorporation of UPR with steel slag composite will be investigated. The UPR composite film will be prepared by the process of milling and pulverization which is to reduce the particles of steel slag. Then the sieving of the following particles will be integrated with UPR and steel slag to form the composite film and it can be used to strengthen the mechanical properties such as stiffness and ductility in the film. The structural, morphology and mechanical properties will be performed by X-ray diffraction (XRD), scanning electron microscopy (SEM) and tensile strength, respectively.

## 1.5 Significances of Study

The UPR composite has been used in various structural applications because of its strong performance in mechanical properties. It also can offer a prospective substitute for conventional plastic films. According to this study, the particle size of steel slag also been known as it impacts the properties such as porosity and flowability. This can be easily useful for determining the most suitable particle size range for a sustainable and cost-effective UPR-steel slag composite film material.

## 1.6 Expected Outcome

In this project, a film will be prepared by the combination of UPR-steel slag composite. It would be expected that the structural, morphology and thermal properties would improve the properties of the film with the assist of steel slag content and its particle size. As expecting in a possible outcome, when combined with steel slag, UPR can create a composite film with improved mechanical and physical properties, such as increased strength, durability, and corrosion resistance.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Steel Slag

In steel-making furnaces, the process of separating the molten steel from impurities results in the production of steel slag, a by-product. Steel slag is a complex mixture of silicates and oxides that forms as a molten liquid melt and solidifies after cooling. Integrated steel plants that use a variation of the basic oxygen process or speciality steel plants (mini mills) that use an electric arc boiler process are currently used to produce almost all steel (Figure 2.1). The basic oxygen process involves charging a converter with hot liquid blast boiler metal, scrap, and fluxes made of lime (CaO) (Shi, 2004). During the process of reducing iron ore through coke in a blast furnace, blast furnace slag is generated while steel making slag is generated in the process of refining a hot metal produced by a blast furnace into steel, and has been mostly used as road material (Tiwari et al., 2016).

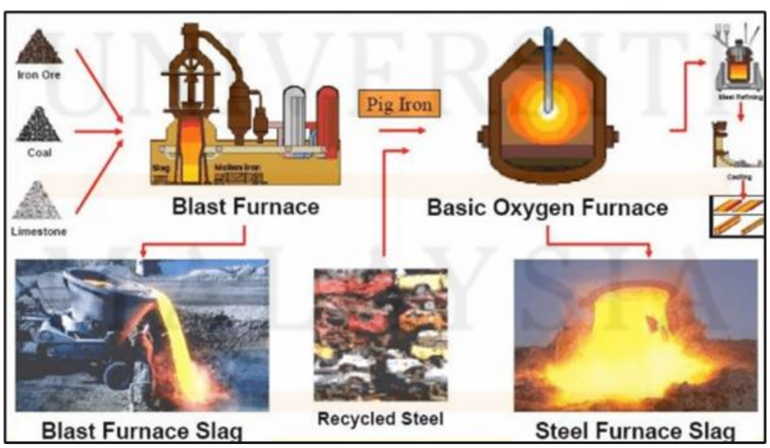


**Figure 2.1**: The process of making steel slag from different furnaces (Tiwari et al, 2016)

The impurities from steel making furnace include carbon in the form of gaseous carbon monoxide as well as liquid oxides of silicon, manganese, phosphorus, and some iron as well as lime, which together create the steel slag (Jha et al., 2008). The liquid steel is tapped (poured) into a ladle at the conclusion of the refining process, while the steel slag is kept in the vessel and is later tapped into a separate slag pot. There are several grades of steel that may be manufactured, and each grade can have drastically different steel slag characteristics (Yi et al., 2012). Depending on the amount of carbon in the steel, grades can be divided into high, medium, and low categories. High-grade steels contain a lot of carbon. More oxygen levels are needed throughout the steel-making process to lower the quantity of carbon in the steel. Moreover, more lime must be added in order to remove impurities from the steel and accelerate slag formation (Martins et al., 2021).

## 2.2 Steel Slag Applications

The steel industry produces large quantities of steel slags as a by-product. Major composition of steel slag is calcium, silicon, ferric, aluminium, and magnesium oxides. They are also consisting of minerals such as larnite, alite, brownmillerite, and ferrite. In addition to wasting precious resources, the dumping of steel slag at landfills also seriously pollutes the environment.

Recently, steel slag is utilised in cement-based composites. The usage of steel slag is being encouraged by promising mechanical and durability results in cement-based composites. Steel slag has a good binding quality between cement particles because they exhibit good morphological when used as an aggregate. However, the mechanical qualities and durability of the composites made from steel slag are greatly endangered by the direct usage of untreated steel slag (Song et al., 2021). Thus, A thorough understanding of the interactions between steel slag and concrete can significantly increase the utilisation of steel slag in concrete (Wang et al., 2013).

## 2.3 UPR Composite

Unsaturated polyesters resin (UPR) is an important class of thermoset polymers. UPR is one of the most used thermosetting polymers that are used extensively due to their low cost, easy processability, good corrosion resistance, and availability in a variety of grades. Products obtained from neat UPR have relatively poor mechanical and thermal properties, which limit their usage in advanced composites. Although the enhancement of flame-retarding efficiency played an important role in the widely application of unsaturated polyester resin composites, its mechanical property cannot be ignored. Generally, the higher the amount of incorporated filler, the worse the mechanical properties. Thus, the amount of filler must be in optimum. Incorporated filler into UPR can be done by directly blending with the matrix resin. Their compatibility and interfacial characteristic affects the mechanical properties of the composites (Hu et al., 2022).

## 2.4 Filler for UPR Composite

Polymer composites are produced using a variety of filler reinforcements for various applications. Thermal, mechanical, and tribological properties of the polymer composite can be improve by addition of fillers such as organic or inorganic fillers such as glass fibers, inorganic minerals, natural and synthetic polymers and others (Kovačević et al., 2017).

### 2.4.1 Steel Slag as Filler in UPR Composite

The fillers could be also come from industrial waste. Steel slag is an industrial waste that commonly used as fillers in epoxy composite (Li et al., 2022) (Erdoğan et al., 2019). These composites could be used for a variety of purposes. Slag is one of the inorganic waste materials obtained from ore processing. In this work, epoxy composites filled with different percentages of slag were prepared (Guzel & Deveci, 2017).

In geopolymer composite, steel slag is the most suited to be used as a supplemental material to create a great property. The uses steel slag as filler effectively and lessen the environmental risks associated with steel slag build up, this relates to the ability to prepare geopolymer materials with mechanical qualities that satisfy pertinent engineering applications (Zhu et al., 2021). The process of making UPR composite can be made by only by mixing of UPR with using compression moulding. Moreover, it has been reported that UPR-steel slag has appropriate strength and rigidity, good water resistance, aging resistance and corrosion resistance (Jones 2017).

### 2.4.2 Factors Affecting the UPR Composite Properties

The primary filler features that have an impact on the properties of composite materials are particle/fibre size, size distribution, specific surface area, and particle form and appearance, which determine the maximum permissible interfacial region between the filling surface and the polymer matrices (Girge, Goel et al. 2021). It is also applicable for steel slag.

### 2.4.3 Steel Slag Content

It is known that in most polymer composite, the optimum content of fillers is required. Filler amount significantly affects the mechanical properties of composite. For example, a study by Guzel & Geveci et al., 2017, various different amount of steel slag (0, 5, 10, 15 and 20 wt%) showed that the specimens containing 20 wt% steel slag have improved water sorption and thermal stability. Also, it has been reported that the composites with various addition 20 wt% steel slag improve the micro-hardness, flexura, wear resistance and tensile strength of the epoxy-composites (Purohit & Satapathy, 2018).

### 2.4.4 Particle Size of Steel Slag

In general, the particle size of the steel slag used in polymer can vary from a few microns to several mm. However, steel slag particles with a maximum size of around 1 mm or less are used in terms of combination with polymer (X. Sun et al., 2022). Smaller particle sizes can increase the surface area of the slag and improves the adhesion between the steel slag and the smaller resulting in a more homogeneous and stronger material. A given volume of material that is available in smaller particles has a greater surface area for solid-liquid contact, so accelerating the dissolution of slag and ultimately the carbonation reaction (Yadav & Mehra, 2017). For example, in the study of filler particles of 300 μm size were used to form the composites using the hand-lay method with mechanical stirring at 180 rpm. Results show improvement in mechanical, flexural, and thermal stability of the composites with increasing weight fraction of the filler (Baciocchi et al., 2009)

# CHAPTER 3

# MATERIALS AND METHODS

## 3.1 Introduction

The unsaturated polyester resin (UPR) will be mixed with steel slag to create a composite at different steel slag content and particle and then followed by characterization of its structural, morphology and mechanical properties. The flowchart of this study is shown in Figure 3.1.

## 3.2 Preparation of steel slag

Prior to milling, n-heptane will be added to powder mixture with 2 wt% of total weight of the steel slag. It will be dry milling method used for powder mixture production. Then, the powder mixture will be milled using a planetary ball milling at 30 h with 300 rpm. During milling, zirconia balls with diameter size 10 mm and balls to powder is 10:1. After milling, the powder was pulverized and sieved at different particle size (45 and 125 µm). The steel slag then will be placed in dry cabinet to prevent moisture. Figure 3.1 shows the flowchart of steel slag preparation.

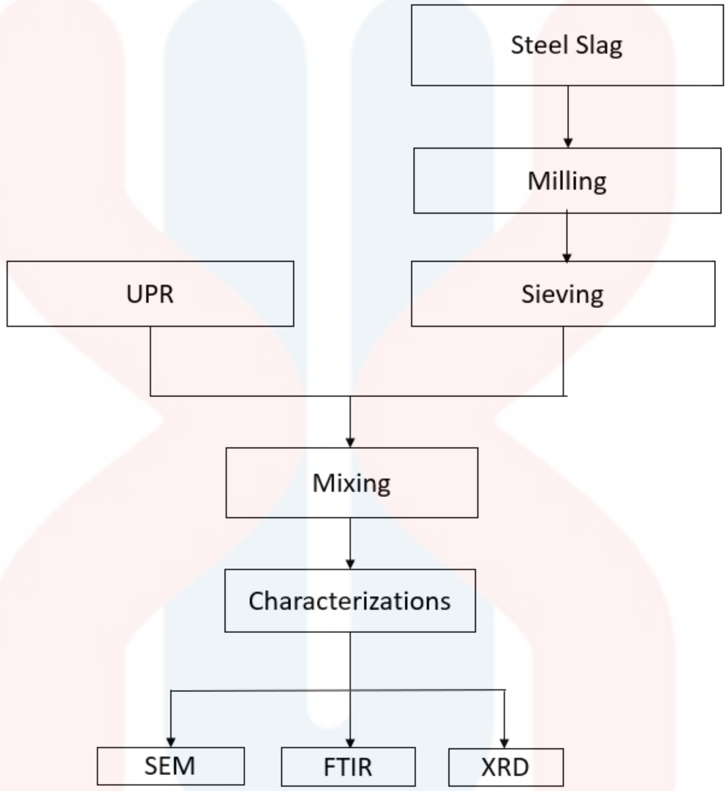


Figure 3.1: Flowchart of the experiment in this study

### 3.3 Preparation of UPR-steel slag composite

Preparation of composite involve of adding steel slag into UPR in a stainless-steel die (15 cm x 15 cm x 0.1 cm). Steel will be added at various content as shown Table 3.1. Then, the composite was pressed at 100 MPa using compression moulding machine.

Table 3.1: Sample designation and composition of UPR-steel slag composites

| Sample designation | UPR (wt%) | Steel slag (wt%) | Particle size steel slag (µm) |
|---|---|---|---|
| UPR3SS45 | 97 | 3 | 45 |
| UPR5SS45 | 95 | 5 | 45 |
| UPR7SS45 | 93 | 7 | 45 |
| UPR3SS125 | 97 | 3 | 125 |
| UPR5SS125 | 95 | 5 | 125 |
| UPR7SS125 | 93 | 7 | 125 |

## 3.4 Characterization and Testing

### 3.4.1 Scanning Electron Microscope (SEM)

Scanning Electron Microscope (SEM) JEOL-JSM IT-100 with secondary electron was used to study the morphology of as-milled steel slag. The sample will be scanned under 100X, 500X and 1000X magnifications.

### 3.4.2 Fourier Transform Infrared Ray (FTIR)

Thermos scientific, USA model Nicolet$^{tm}$ iS$^{tm}$ 10 FTIR spectrometer was using to examine the functional group in UPR-steel slag composite. Each sample of will be scanned at 16 steps from 400-4000 cm$^{-1}$ with the resolution of 2 cm$^{-1}$. In the transmittance mode, spectral outputs will be captured as a function of wave number.

### 3.4.3 X-Ray Diffraction (XRD)

Phase identification of UPR-steel slag composite determined using X-ray Diffraction (XRD) (Bruker D2 Phaser). The step size was fixed at 0.02° with the 2θ angle of 20° to 90°. Software DIFRAC.EVA was used for phase identification to perform analysis on XRD pattern of the composite.

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 X-ray Diffraction

Figure 4.1 shows the XRD patterns of as-milled steel slag and UPR-SS composites. In as-milled powder, the peaks corresponding to wuestite, larnite, tridymite, and mayenite were observed in the patterns which signify a complex amalgamation of constituents in the steel slag. The presence of wuestite (COD No.1011168), suggests the steel slag containing iron (II) oxide (FeO), originating as main component in the steel slag. Wuestite also can be found in all composite's peak patterns. This indicates the incorporation of iron-rich phases within the composite. Second components that commonly exists in the steel slag is silicates. In these XRD patterns, the appearance of peaks associated with larnite, a calcium silicate ($Ca_2SiO_4$), indicates the presence of this phase after milling for 30 h. The sources of these silicate phases may include both UPR and the steel slag.

The effect of the amount of steel slag on peak intensity remained unchanged, while increasing particle size resulted in lower intensities of steel slag phases and increased the crystalline peak of UPR. The peak intensities of larnite (33.4°) and wuestite (36.6°) could not be resolved with 125 µm steel slag. In XRD, the diffracted intensities depend on particle size of the sample. As particle size increases, the XRD peak height increases due to random crystals orientations is higher (Sun et al., 2022).

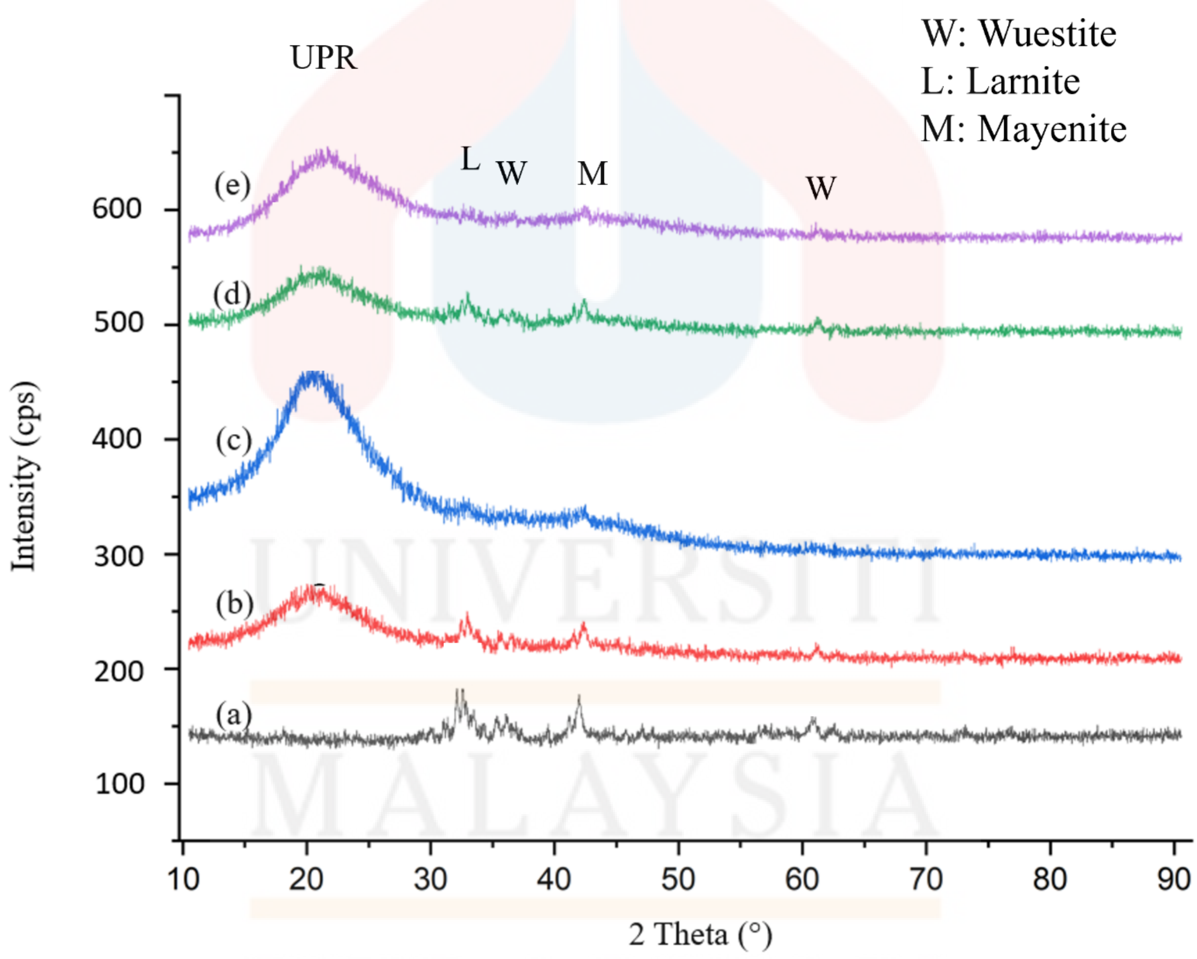


Figure 4.1: XRD patterns of (a) as-milled steel slag and composites (b) UPR3SS45 (c) UPR3SS125 (d) UPR7SS45 (e) UPR7SS125

Figure 4.2 shows the crystalline and amorphous percentage of UPR-SS composites determined by XRD. Increased of SS loading from 3 to 7 wt% in UPR matrix increased the crystallinity of the composites. The composite was highly crystalline with composites having 125 µm steel slag particles compared to 45 µm. Using small 45 µm steel slag particles improved the formation of crystals and reduced the size of grains in the UPR matrix.

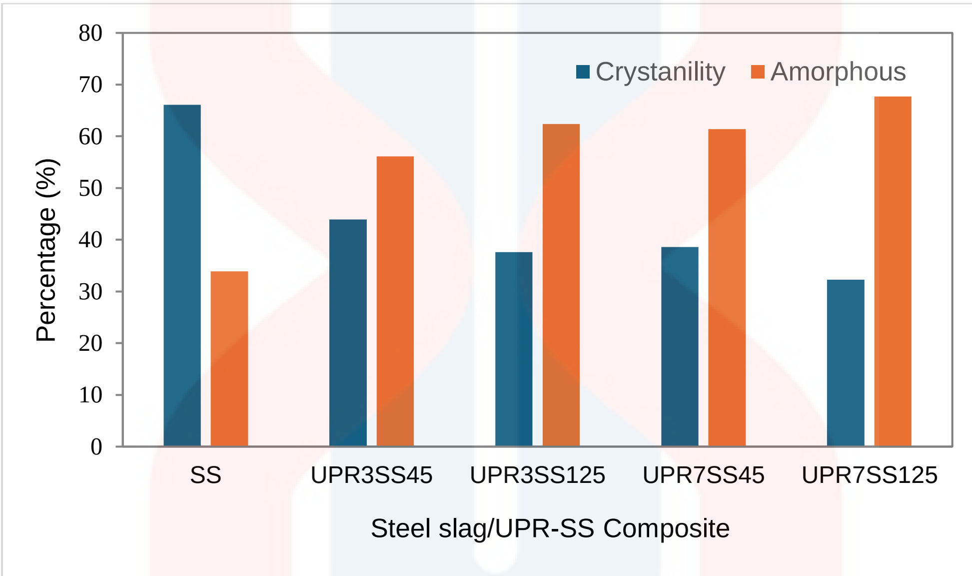


Figure 4.2: Percentage of crystallinity and amorphous of as-milled steel slag and UPR-SS composites

## 4.2 Fourier Transform Infrared Spectroscopy

FTIR spectra of the UPR-SS composites at different steel slag compositions and particle size is shown in Figure 4.3. The peaks at 3200 to 3500 $cm^{-1}$ regions attributed to O-H stretching vibrations of hydrogen bonded hydroxyl (OH) interactions which was commonly found for UPR. However, these peaks were almost invisible as result of molecular interaction of hydroxyl group with steel slag and surrounding moisture. The band observed at 2900 $cm^{-1}$ is assigned as C-H stretching. Moreover, the spectra related to UPR also found around 1700 $cm^{-1}$ indicating the C=O stretch that signifies the presence of carbonyl groups. Variations in the intensity and position of this peak across different compositions of the composite can be indicative of changes in the UPR content or alterations in the chemical environment of the carbonyl groups. The region around

1200-1400 cm⁻¹ are assigned as C-N stretch which contributed from the presence of nitrogen-containing functional groups, offering information about potential additives or modifications in the UPR-SS composite. The C-H bend, typically observed in the region around 1450-1470 cm⁻¹, is associated with the bending vibrations of hydrogen atoms in aliphatic hydrocarbon chains. This peak can be particularly informative when studying the aliphatic nature of the UPR and its interaction with the steel slag. The variations in this peak across different compositions can reflect changes in the hydrocarbon backbone of the composite.

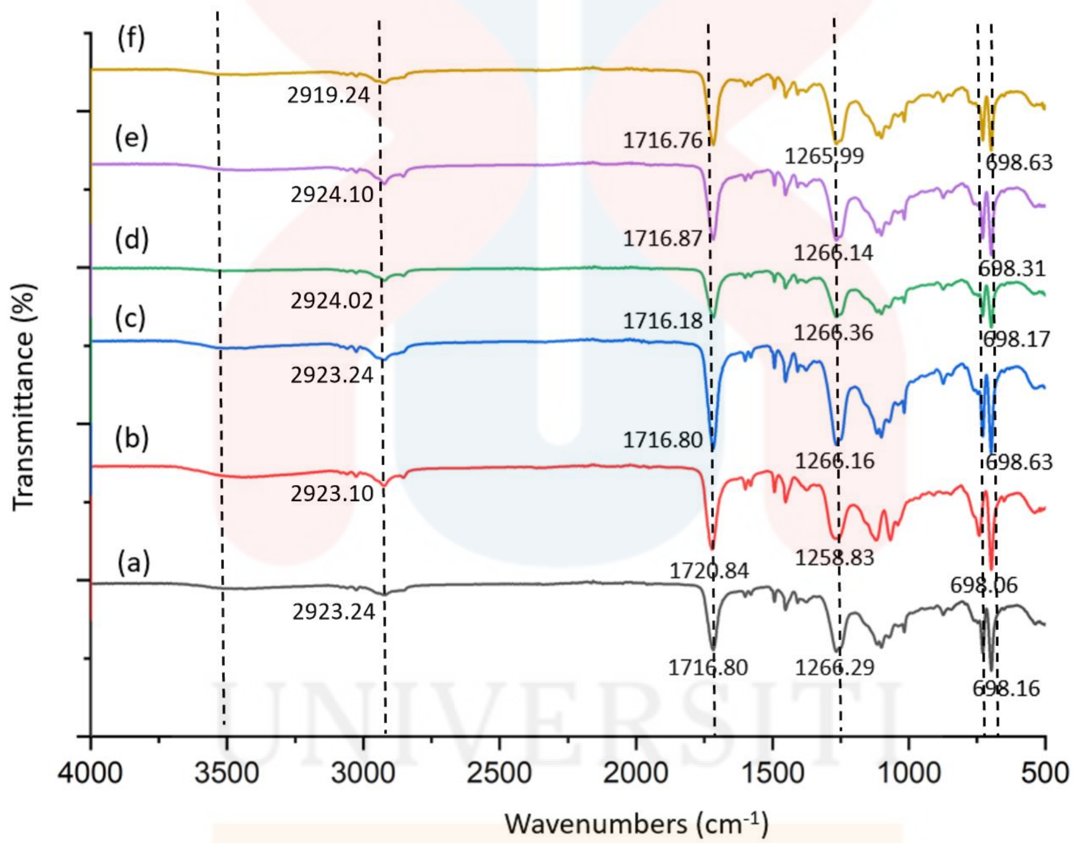


Figure 4.3: FTIR spectra of UPR-steel slag composites (a) UPR3SS45 (b) UPR3SS125 (c) UPR5SS45 (d) UPR5SS125 (e) UPR7SS45 (f) UPR7SS125

The effect of particle size on functional group of the UPR-SS composites caused the broadening of the FTIR spectra. It was indicated that the composite with 125 µm are more likely have reduce absorption than the composite with 45 µm steel slag. This is because the width, intensity, and area of bands in FTIR spectra of composites are directly dependent on particle size. As particle size increases, the intensity and location of IR bands tends to decrease as bandwidth rises (Sun et al., 2022; Udvardi et al., 2017). In addition, the use higher amount of steel slag produces a slight shift of the IR band for -CH stretching (around 2923 $cm^{-1}$).

## 4.3 Scanning electron microscope

### 4.3.1 As-milled steel slag

Figure 4.4 shows the SEM image of the as-milled steel slag with 45 µm after fine refining and sieved. When the steel slag is milled, the SEM image reveals a rich-side iron oxide particle with a size of 45 µm. This occurs after the steel slag has been finely refined and sieved. An irregular shape and a rough surface are both characteristics of the particle. Milling is a process that reduces the size of the steel slag into smaller particles. The presence of rich-side iron oxide in the steel slag that has been milled to a size of 45 µm after being finely refined and sieved is likely to have a detrimental effect on the properties of the steel slag. The probability of degradation of steel slag increases when brittle particles are present.

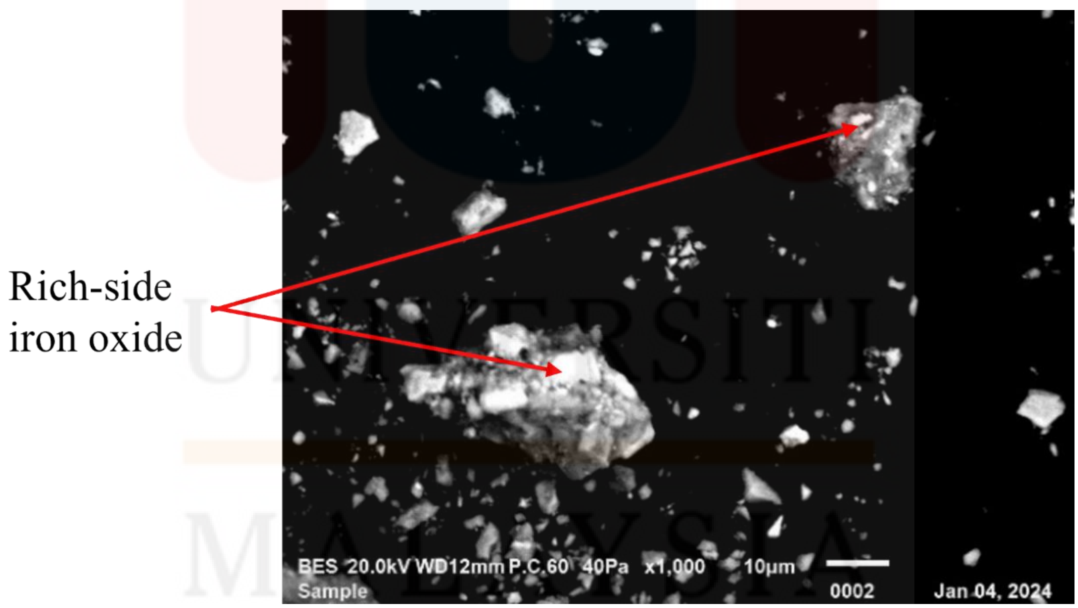


Figure 4.4: SEM images of as-milled steel slag after pulverizing and sieved for 45 µm

### 4.3.2 UPR-steel slag composites

SEM images of the UPR-SS composites at different steel slag compositions and particle size is shown in Figure 4.4. The microstructure of all composites shows the interactions steel slag between the UPR matrix. It was found that steel slag was embedded in UPR matrix. When it comes to the morphology and size distribution of the pores in the composites, the particle size and volume fraction of UPR have a significant impact on the formation of the pores. The higher the amount of steel slag produced more embedded particles in UPR. Both the UPR3SS45 and the UPR3SS125 composites (Figures 4.4 a) and b) have SS particles that are relatively uniformly distributed throughout the steel matrix. These UPR particles are relatively small. In addition, the pores in these composites are quite small and are distributed in a uniform manner. This leads one to believe that the small UPR particles serve as nucleation sites for pores during the solidification process, and that the uniform distribution of the particles results in a uniform distribution of pores. Incorporating SS into UPR matrix with particle sizes of 45 μm produce a homogenous distribution than the 125 μm steel slag. It was shown that the composite containing 125 μm consist of agglomerated particles which obvious seen in Figure 4.4 f).

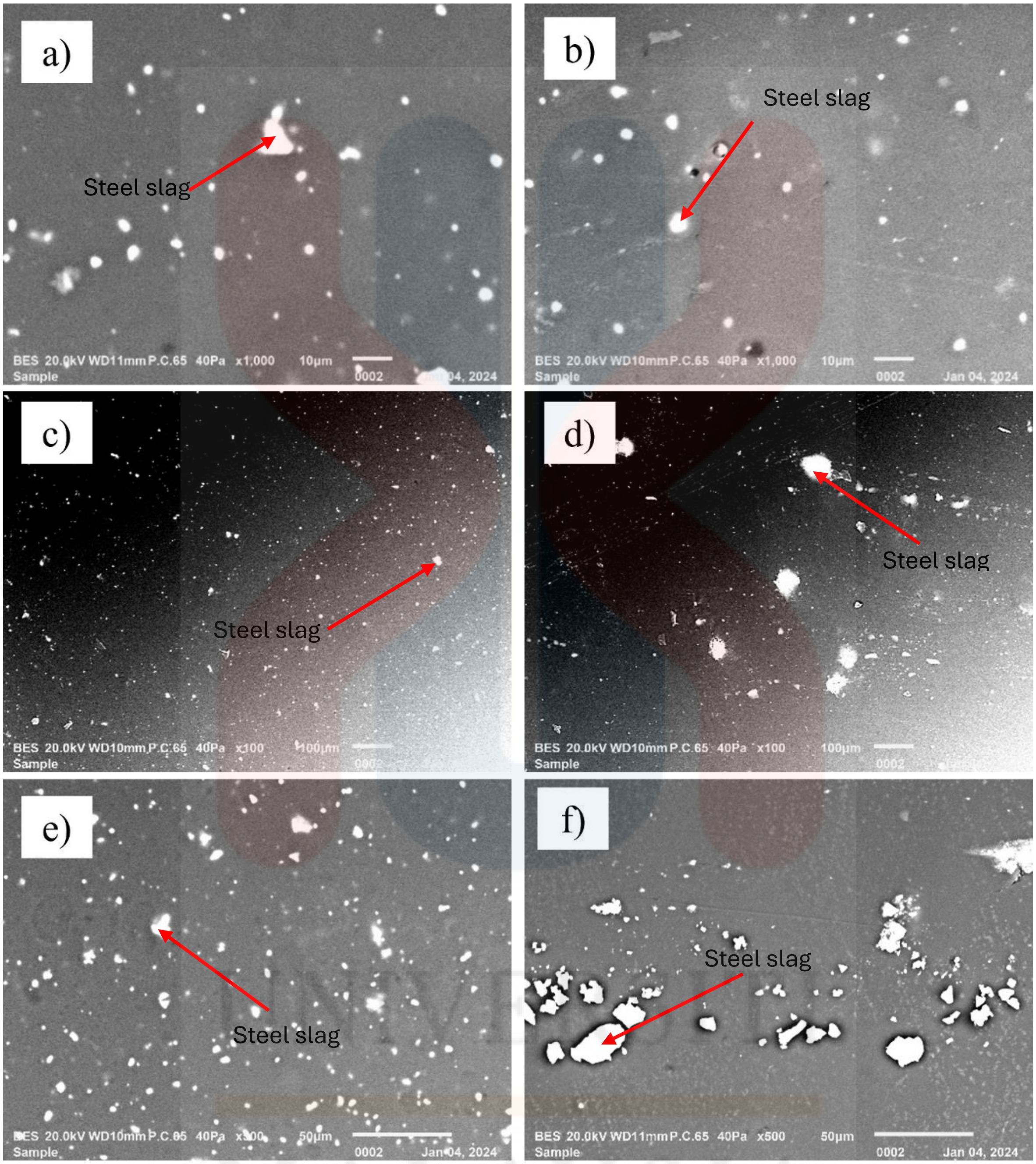


Figure 4.5: SEM images of UPR-steel slag composites a) UPR3SS45 b) UPR3SS125 c) UPR5SS45 d) UPR5SS125 e) UPR7SS45 f) UPR7SS125

# CHAPTER 5

# CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusion

Preparation of UPR-SS composites with different amounts and sizes of steel slag has been successfully produced. The characterization of phase identification, crystallinity, morphology of the as-milled and UPR-SS composites were studied. The findings and conclusion drawn from this study are:

- The as-milled differences steel slag was found having major components of iron oxide and silicates. The crystallinity of the composites was influenced by the amount of steel slag loading and particle size.
- Larger steel slag particles result in composites with reduced absorption of FTIR spectra compared to smaller particles.
- The study reveals that steel slag is encapsulated within the UPR matrix of all composites, thus establishing a strong interaction between them.

## 5.2 Recommendation

The UPR-steel slag composite will be thoroughly prepared using compression moulding, an established method that guarantees consistency and repeatability in the creation of composite materials, in order to fulfil the goals stated in this thesis. Throughout the manufacturing process, the UPR matrix's steel slag content and particle size will be systematically changed. The objective of this systematic approach is to generate a set of composite samples that include a variety of compositions, enabling a thorough examination of the impact of steel slag on the final product. Sophisticated analytical methods like X-ray diffraction (XRD) for phase identification, I did the physical properties of these composites and provide insight into their crystalline structure. Furthermore, the morphology of the composites will be examined using scanning electron microscopy (SEM), which will provide information on the material's microstructure. The mechanical strength, thermal conductivity, and heat resistance of the UPR-steel slag composites will be methodically measured and examined at various particle sizes and percentages of steel slag content. Fourier-transform infrared (FTIR) spectroscopy will be used for phase identification and morphology analysis in order to thoroughly assess the chemical composition of the UPR-steel slag composites. Comprehensive understanding of molecular interactions, polymerization, and structural alterations in the composite materials will be possible through FTIR characterization. This study aims to provide a comprehensive understanding of the phase identification, morphology, and physical properties of the UPR-steel slag composites at different steel slag content percentages and particle sizes by combining FTIR with other analytical methods. The addition of FTIR analysis will improve chemical characterization's depth and precision, leading to a deeper understanding of the structure and possible uses of the composite. It is anticipated that this comprehensive approach will produce a complex comprehension of how variations in steel slag characteristics affect the composite material's overall performance and suitability for different engineering applications. The results of this study will provide important new information to the field of composite materials and could direct the creation of high-performance, environmentally friendly building materials in the future.

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