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Compressive Strength of Concrete with Nickel Carbon Sulfur and Dirty Sulfur Waste Substitution: A Unit Price Analysis (AHSP) Approach

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Abstract:
Nickel is one of the minerals that is in high demand by many parties, especially now that nickel is an important ingredient in promoting green energy because it is a key component in electric vehicle production. According to the International Energy Agency (IEA), nickel demand in 2020 was 2,340.56 metric tons, and according to the sustainable development scenario, nickel demand is projected to reach 6,265.74 metric tons, which could account for 60% of total clean energy by 2040. However, the environmental impact of this mining includes cases of environmental damage such as road damage, water pollution, air pollution, and land degradation. Based on the Regulation of the Minister of Environment and Forestry Number 6 of 2021 concerning Procedures and Requirements for the Management of Hazardous and Toxic Waste Materials, the determination of the status of B3 waste is carried out through characteristic tests which include explosive, flammable, reactive, infectious, corrosive, and/or toxic properties. TCLP tests, LD50 toxicology tests, and sub-chronic toxicology tests were performed to determine the toxic properties of B3 waste. The method used in this study involved concrete mix design as an advanced processing technique for cement/concrete manufacturing. This research is experimental and aims to determine the relationship between the compressive strength of concrete and compression testing using the concrete mix design method. The test specimens made in this experiment were concrete cylinders with a height of 300 mm and a diameter of 150 mm, totaling 150 samples with curing periods of 7, 14, 28, 54, and 90 days. Carbon sulfur and dirty sulfur were determined to be non-B3 waste based on the results of the TCLP test, allowing for further processing and utilization. Carbon sulfur and dirty sulfur from laboratory test results showed that the toxicity characteristic leaching procedure (TCLP) and total concentration (TK) values did not exceed the Category B threshold according to PP22 of 2021, classifying them as non-B3 waste and enabling their utilization. For the 90-day curing period, the highest compressive strength was achieved with cs+ds 5% and cs+ds 10% at 179.4 kg/m² and 170.3 kg/m², respectively. The economic value for each mixture was: Cs+Ds 5% at IDR 34,042.50, Cs+Ds 10% at IDR 36,941.14, and Cs+Ds 15% at IDR 39,495.52.

Keywords: *Carbon Sulfur, Dirty Sulfur, Solid Waste*

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INTRODUCTION

Environmental damage remains a major issue discussed across different levels of society to identify solutions and review government policies related to environmental aspects (Harper & Snowden, 2017). It is characterized by the deterioration of soil, water, and air quality; the extinction of wild flora and fauna; and the destruction of ecosystems (Shivanna et al., 2022; UNEP, 2025). The causes include natural potential hazards such as earthquakes triggered by crustal plate movements and extreme weather events, including heavy rainstorms driven by high sea surface temperatures (Gao et al., 2025; USGS, 2024). Land degradation caused by vegetation loss, erosion, and salinization further accelerates environmental deterioration (European Commission, 2024; Phillips et al., 2024; NOAA, 2025). Landslides also occur as a result of soil structure erosion induced by heavy rainfall and ecological degradation (Gao et al., 2025).

The advancement of human knowledge and civilization along with technological developments in various sectors continues to intensify with the goal of facilitating societal activities. Indonesia's nickel mining industry is currently experiencing significant growth due to huge market demand and investment, driven by social and technological advancements that utilize nickel (Ni) as a primary raw material in lithium-ion battery production for eco-friendly transportation (IEA, 2023; Guberman, 2024). Nickel is one of the most demanded minerals, especially with its critical role in promoting green energy as an essential component in electric vehicle manufacturing (IEA, 2024; IEEFA, 2024). According to IEA data, nickel demand in 2020 was around 2,800 kt (2,800,000 metric tons), and under the Net Zero Scenario, it is projected to rise to approximately 5,689 kt by 2040 (IEA, 2025). Indonesia holds substantial nickel reserves—72 million tons or about 52% of global reserves—which has encouraged the government to progress with downstream prioritization, including a ban on nickel ore exports effective January 1, 2020 via Minister of Energy and Mineral Resources Regulation Number 11 of 2019 (AEER, 2024). The government has also targeted building 53 smelter units by 2024 and offered fiscal facilities such as import duty relief, tax allowances and holidays, regional incentives, and infrastructure access to transform Indonesia into not just the largest producer of nickel, but also a manufacturer of nickel-processed products (USITC, 2024; Guberman, 2024). However, large-scale nickel mining raises environmental concerns in mining areas and surroundings due to suboptimal upstream and downstream production management and insufficient attention to resulting environmental impacts (IEEFA, 2024; OSF RePEc, 2023).

In the case of environmental damage due to nickel mining, as in the journal written by Septianto Aldiansyah and La Ode Nursalam, it has been clearly known to have an impact on environmental damage such as road damage, river water pollution/watershed contamination, air pollution, land destruction, damage to flora and fauna, and social impacts such as changes in community behavior and lack of public health empowerment. The results of the journal's research found environmental damage due to nickel mining which only has an impact on the environment and society but did not discuss other factors causing environmental damage in social, economic, and political aspects. Another causal condition when further analyzed turns out that environmental damage is not only caused by natural environmental conditions alone, but there are social and political factors. The environmental problems that occur cannot be separated from the debate factor on the implementation of the concept of environmental ethics, which to this day is still a tug-of-war between anthropocentrism and ecocentrism. Departing from these two concepts, it determines the government's policies and perspective in managing the environment. If you look at government programs and policies and examine the environmental impacts that occur, anthropocentrism still dominates the government's perspective in environmental management with consideration of profit and development values.

One of the wastes produced in nickel ore mining activities is in the form of *Carsul*, which comes from sulfur smelter, which is a source of minerals that can be reprocessed. Currently, *Carsul* has not been used internally by PT. Vale Indonesia Tbk. With a content of 88% sulfur, 11% *CaO*, and 1% Fe and Mn in *Carsul*, it can be recycled into new products. In the wastewater produced by nickel mines, by-products or residual substances are always produced in the form of solids or liquids; this must occur in the process of breaking down the lump to get the nickel core in it. This is usually done in the pressing machine process, where this process aims to break the nickel so that the nickel in the block can be extracted, or it is a separation process between nickel and the block that adheres to the nickel. The results of the pressing machine process will produce residual substances which, in general, in the mining world are referred to as *Carsul*, and this language is not used in *KBBI* because the language is terminology that circulates in the world of the mining industry.

Carsul has sulfur content as much as 88% of the total substances in *Carsul*, so it can potentially be a basic adsorbent to reduce contaminant levels, but before the use of *Carsul* as a coagulant to reduce hexavalent chromium levels, research needs to be conducted to determine the efficiency of *Carsul* for the removal of hexavalent chromium. The initial characteristic of *Carsul* is sludge cake, and when this characteristic is left for a long time, it will turn into a solid that is quite hard and almost resembles a rock. This makes the *Carsul*, before processing, need to be crushed first in order to achieve a smooth character and be easy to process for mixing in the wastewater left over from production in the nickel mining industry of PT. Vale Indonesia, Tbk.

Based on the Regulation of the Minister of Environment and Forestry Number 6 of 2021 concerning Procedures and Requirements for the Management of Hazardous and Toxic Waste Materials, the determination of the status of *B3* waste is carried out through characteristic tests which include explosive, flammable, reactive, infectious, corrosive, and/or toxic properties. The TCLP test, LD50 toxicology test, and sub-chronic toxicology test (*LHK RI*, 2021) were carried out to determine the toxic properties of *B3* waste. Carbon sulfur and dirty sulfur are determined as non-*B3* waste based on the results of the TCLP test so that further processing and utilization can be carried out. There are two advanced processing options, namely solidification for final disposal and cement/concrete manufacturing for road bases or other concrete products. Treatment with stabilization or solidification aims to relocate solid waste to be stored in the final landfill area. Processing into cement or concrete aims to utilize solid waste as a material for civil engineering purposes, for example in terms of road pavement (road base) and concrete products (paving blocks, bricks, culverts, and barriers).

Admixtures are materials that are added to the concrete mixture before or during mixing. The function of this material is to change the properties of the concrete to make it more suitable for a particular job or to save costs. An admixture or additive defined in the Standard Definitions of Terminology Relating to Concrete and Concrete Aggregates (ASTM

C.125-1995) and Cement and Concrete Terminology (ACI SP-19) is a material other than water, aggregate, and hydraulic cement mixed in concrete or mortar that is added before or during stirring. Additives are used to modify the properties and characteristics of concrete, for example, to be easily workable, accelerate hardening, increase compressive strength, achieve savings, or for other purposes such as energy saving. Additives are usually given in relatively small amounts and must be under strict supervision so as not to overdo it, which will actually worsen the properties of the concrete (Mulyono, 2004).

This research is motivated by the existence of solid carbon sulfur and dirty sulfur waste that accumulates due to limited storage land, even though it is classified as non-*B3* waste that can actually still be used. Potential further uses include solidification for final disposal as well as additional materials in the production of cement/concrete for road bases or other concrete products, which are not only environmentally friendly but also economically valuable. Based on this, this study formulates problems related to the effect of mixed carbon sulfur and dirty sulfur with variations of 5%, 10%, and 15% on the compressive strength of concrete and its cost value, as well as calculating the volume of waste that can be used for the needs of road rigid pavement.

Previous research by Septianto Aldiansyah and La Ode Nursalam (2020) demonstrated the environmental consequences of nickel mining, including road damage, river pollution, and social disruption. However, this study was limited to the analysis of environmental and social impacts without exploring the potential use of nickel industry waste as construction material or in environmentally friendly technologies. Another study by Mulyono (2004) highlighted the use of additives in concrete to improve strength and cost efficiency, but it did not specifically examine the integration of nickel mining waste. From these studies, a clear research gap emerges: there is a lack of studies combining technical aspects (concrete compressive strength) and economic analysis (cost efficiency) in utilizing *Carsul* waste for rigid pavement construction.

The novelty of this study lies in its focus on the utilization of *Carsul* waste from nickel mining as a concrete additive for rigid pavement, with mixture variations of 5%, 10%, and 15%, analyzed in terms of both compressive strength and cost. This research addresses the gap by linking sustainability, economic efficiency, and optimal non-hazardous waste management, offering added value not only to the nickel mining industry but also to the construction sector and environmental management.

The scope of the study used waste samples from PT Vale Indonesia in Soroako, Central Sulawesi, with concrete compressive strength testing carried out at WIKA Pratama Learning Centre, Cibubur, and cost analysis referring to regulations of the Ministry of Public Works (2022). The purpose of the research is to obtain an optimal formulation of waste mixture from a technical and economic point of view, as well as to provide information to PT Vale Indonesia about the benefits of using this waste. The results of the research are expected to provide practical recommendations related to improving concrete quality, cost efficiency, and positive contribution to the environment and society through sustainable waste utilization.

RESEARCH METHOD

This study uses a quantitative method with an experimental design to analyze the effect of adding solid waste of carbon sulfur (CS) and dirty sulfur (DS) on the compressive strength of concrete and its cost implications. Samples were taken from PT Vale Indonesia (Sorowako) and tested at the WIKA Pratama Learning Center (Cibubur) Laboratory using concrete cylinder test specimens (Ø15 cm × 30 cm) totaling 150 samples with variations in curing ages of 7, 14, 28, 54, and 90 days. Concrete formulations include normal (control) concrete, concrete with additional CS, DS, and CS+DS combinations, which are analyzed in terms of compressive strength and cost using the *AHSP* method. The research process includes sampling, preparation (sieving, grinding, homogenization, and quartering), characteristic testing (specific gravity, moisture content, aggregate gradation), manufacturing test objects, slump testing, and compressive strength tests with compression testing machines. The data are analyzed comparatively through tabulation and graphs to evaluate the difference in performance between normal concrete and waste concrete, as well as to calculate the cost efficiency and potential utilization of waste for road rigid pavement.

Table 1. Research Stages

Research Stage	Main Activities
Problem Identification	Slow execution of manual queries, utilization of CS & DS waste as an additive
Literature Studies & Theoretical Studies	Analysis of previous research, concrete theory, waste utilization
Sampling	CS & DS sampling at PT Vale, preparation (sieving, grinding, homogenization, quartering)
Characteristic Testing	Specific gravity, moisture content, aggregate gradation, concrete material inspection
Manufacture of Test Pieces	150 concrete cylinder samples, variation of peram life (7–90 days)
Laboratory Testing	Slump test and compressive strength test of concrete (compression test)
Data Analysis	Tabulation & graphs, comparative analysis of normal concrete vs waste concrete
Cost Calculation	AHSP analysis, economic valuation of CS & DS waste utilization

Table 1 above summarizes the research flow starting from problem identification, sample collection and preparation, material characteristics testing, manufacturing test objects, to laboratory testing and data analysis. This study emphasizes on the evaluation of concrete compressive strength and cost efficiency due to the addition of *carbon sulfur* and *dirty sulfur waste*, as well as examining its potential use in road construction as a solution for the utilization of non-B3 waste.

RESULTS AND DISCUSSION

Total concentration and TCLP

The results of the determination of the total concentration (TK) and *toxicity characteristic leaching procedure* (TCLP) for *carbon sulfur and dirty sulfur are* presented in accordance with Government Regulation No. 22 of 2021 concerning the Implementation of Environmental Protection and Maintenance (Appendix XIII) and Regulation of the Minister of State for the Environment No. 6 of 2021 concerning Procedures and Requirements for B3 Waste Disposal. Presented in Table 4.1. The values of TK and TCLP for both *carbon sulfur* and *dirty sulfur* are below the total concentration of B (TK B). However, for *dirty sulfur* there is one parameter, namely nickel, whose value is above TCLP C and three other parameters, namely nickel, TPH C10-C36 and total PCBs whose value is above TK C. The value of TCLP *dirty sulfur* for nickel is 2.86 mg/L (TK C threshold = 1.4 mg/L). Meanwhile, the total value of *dirty sulfur* concentration for nickel, TPH $C_{10\text{-}C36}$ and total PCBs was 123, 1040, and 0.04 mg/kg respectively, where the threshold values of TK C were 60, 1000 and 0.02 mg/k, respectively.

LOI and TCLP Test Results

The results of the laboratory test determination show that the *toxicity characteristics leaching procedure* (TCLP) and total concentration (TK) values do not exceed the Category B threshold according to PP22 of 2021. Thus, *carbon sulfur* and *dirty sulfur waste* has the potential to be utilized Based on TGA analysis, the incandescent loss value for *carbon sulfur* and *dirty sulfur waste* is less than 10% if the calculation is carried out after the sulfur evaporation stage. From within the waste matrix. Therefore, in order to avoid confounding the presence of sulfur to LoI, it is necessary to conduct TGA analysis on products from CS and DS formulations both for solidification/stabilization and *concrete filler road base*.

Formula *Job Mix Design* Beton

Waste carbon sulfur (CS) and *dirty sulfur* (DS) are used as *fillers* and substitutes in fine aggregates of concrete forming materials. The effect of the addition *of carbon sulfur* and *dirty sulfur* on the concrete mixture was observed with a fermentation period of 7, 14, 28, 54 and 90 days. Table 4.2 shows the design mix plan of CS, DS and a mix of CS and DS. CS and DS 5%, 10% and 15%. This percentage refers to the number of samples brought from PT. Vale Indonesia as much as 425 kg with a combination of Cs of 200 kg and Ds of 225 kg.

Table 2. Mix Design Concrete Formulation F'c 25

Formulation	Semen (Kg)	Fine Aggregate (Kg)	Coarse Aggregate (Kg)	Water (Liter)	Cs Filler (Kg)	Cs Fine Aggregate (Kg)	Ds Filler (Kg)	Ds Fine Aggregate (Kg)
Beton Normal F'c 25	366	700	1.047	205	0	0	0	0

Formulation	Semen (Kg)	Fine Aggregate (Kg)	Coarse Aggregate (Kg)	Water (Liter)	Cs Filler (Kg)	Cs Fine Aggregate (Kg)	Ds Filler (Kg)	Ds Fine Aggregate (Kg)
Beton + (Cs + Ds 5%)	366	685	1.050	205	6,1	7	12,2	7
Beton + (Cs + Ds 10%)	366	672	1.048	205	12,2	14	24,4	14
Beton + (Cs + Ds 15%)	366	654	1.047	205	18,3	21	36,6	21

Source : Data Processing (2023)

CS and DS waste is aggregated first before mixing. As shown in Table 4.3 each waste will be filtered using filters Nos. 30, 50, 100 and 200.

The implementation of making concrete mixtures with the addition of CS and DS was carried out in the Wika Pratama Learning laboratory. The composition of the concrete mixture is made based on the planning of the concrete mixture that has been made. For each cylindrical test sample that has been made, as presented in Figure 4.5 to Figure 4.8, maintenance will be carried out and stored until the predetermined test life, namely 7, 14, 28, 54 and 90 days. The normal concrete *design job mix* planning is used as a comparison or control over the formulation to be made The normal concrete mix design job that has been determined is Fc 25 and the planning details

After *curing* for a specified period, at the specified test age the concrete mix *formulation* is subjected to a compressive *strength*, in kg/cm2 units, of the concrete mixture that has been made.

Normal Concrete Formulation

This normal concrete formulation is a control formulation for other formulations, as well as for other sample test results. This normal concrete formulation is also a reference for the analysis of compressive strength and cost per m3. The details of the formulation and the results of the compressive strength test can be seen in Table 4.6 below

1. Cement : 366 kg
2. Sand : 700 kg
3. Split/ Coarse aggregate : 1047 kg
4. Water : 205 liters
5. Slum Plans : 12 cm
6. Slump Actual : 10 ± 2 cm

Of the 15 samples that have been prepared, they are categorized into 5 periods of fermentation, namely 7, 14, 28, 54 and 90 days, for each of the 2 strong ferments, 3 samples are prepared to be tested, this is to see the pattern of the characteristics of the concrete and the treatment process between sample 1 and the other, besides that it also serves as a sample reserve if the concrete treatment process is not in accordance with the applicable terms and conditions.

The compressive strength curve compared to the compressive strength of the curve for the age of 28 days there is only 1 formulation whose compressive strength exceeds the compressive strength of normal concrete, Cs+Ds 5% formulation of 252.2 kg/cm² and Cs+Ds 10% formulation of 236.2 kg/cm².

Concrete Formulation + (Cs + Ds 5%)

The manufacture of concrete with the addition *of carbon sulfur* + *dirty sulfur* 5% has the following material composition:

1. Cement : 366 kg
2. Sand : 685 kg
3. Split : 1050 kg
4. Water : 205 liters
5. Cs as filler : 6.1 kg
6. Ds as filler : 12.2 kg
7. Cs fine aggregate substitution : 7 kg
8. Ds fine aggregate substitution: 7 kg

In this composition, the author tries to combine Cs and Ds to find alternative formulations that can be used to increase the compressive strength of concrete.

Concrete Formulation + (Cs + Ds 10%)

The manufacture of concrete with the addition *of carbon sulfur* + *dirty sulfur* 10% has the following material composition:

1. Semen : 366 kg
2. Sand : 669 kg
3. Split : 1048 kg
4. Water : 205 liters
5. Cs as filler : 12.2 kg
6. Ds as filler : 24.4 kg
7. Cs fine aggregate substitution : 14 kg
8. Ds fine aggregate substitution: 14 kg

Formulation + (Cs + Ds 15%)

The manufacture of concrete with the addition *of carbon sulfur* + *dirty sulfur* 5% has the following material composition:

1. Semen : 366 kg
2. Pasir : 654 kg
3. Split : 1047 kg
4. Air : 205 liters
5. Cs as filler : 18.3 kg
6. Ds as filler : 36.6 kg
7. Cs fine aggregate substitution : 21 kg

8. Ds fine aggregate substitution: 21 kg

Cost Analysis of All Formulations

From the results of the compressive strength test of all the formulations that have been determined and the analysis of the unit price of work that has been calculated in relation to the costs incurred can be seen in Table 3 below

Table 3. Compressive With 28 and 90 Days Fermentation Time

Formula	Compressive Strength 28 days (kg/cm²)	Strong Tensile Lifespan 90 Days (kg/cm²)	Cost (Rp/m³)
USUAL	234,55	233,16	**1.156.177,000**
CS + DS 5%	193,37	252,15	1.122.134,499
CS + DS 10%	176,76	236,20	1.119.235,859
CS + DS 15%	145,89	188,64	1.116.681,476

Source : Data Processing Results (2023)

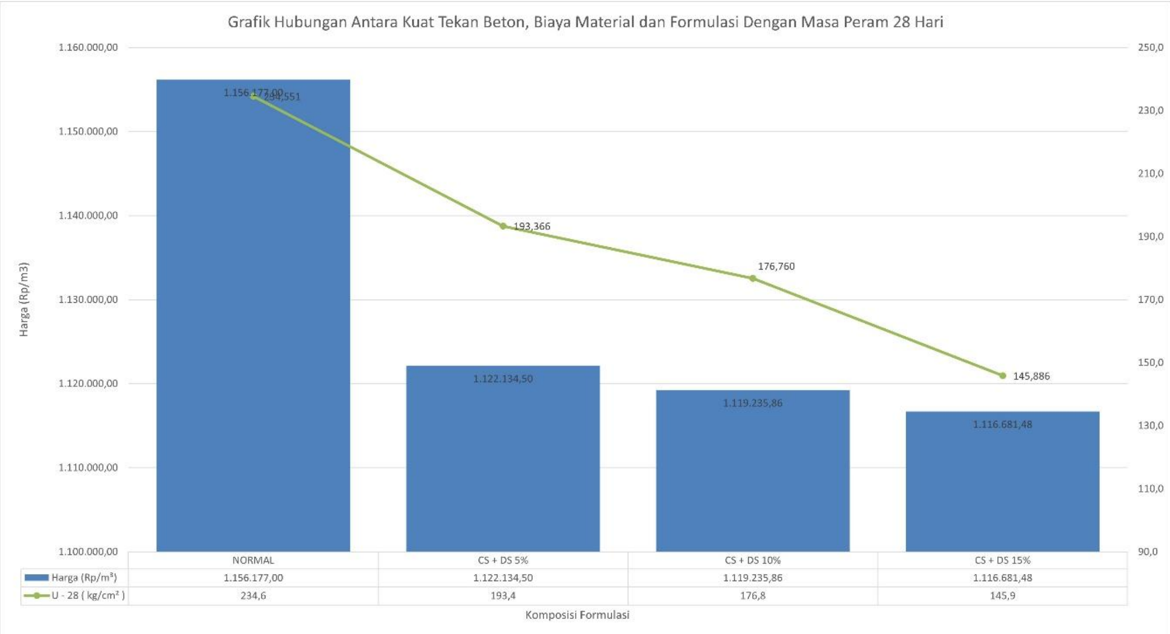

Figure 1. 28 Day Lifespan Strength Relationship Chart, Formulation and Cost

From Figure 1 at the age of 28 days, The provided chart illustrates an inverse relationship between cost and compressive strength in concrete formulations over a 28-day curing period. As the percentage of “CS + DS” additives increases (from 0% in “NORMAL” to 5%, 10%, and 15%), the material cost per cubic meter consistently decreases, ranging from Rp 1,156,177.00 for “NORMAL” concrete down to Rp 1,116,681.48 for “CS + DS 15%.” Conversely, the concrete’s compressive strength (U-28 kg/cm²) shows a corresponding decline, from 234.6 kg/cm² for “NORMAL” to a low of 145.9 kg/cm² for “CS + DS 15%.” This data highlights a clear cost-strength trade-off, indicating that while additive use can reduce material expenses, it simultaneously compromises the concrete's structural integrity, thus necessitating a balanced approach based on specific project requirements and performance expectations.

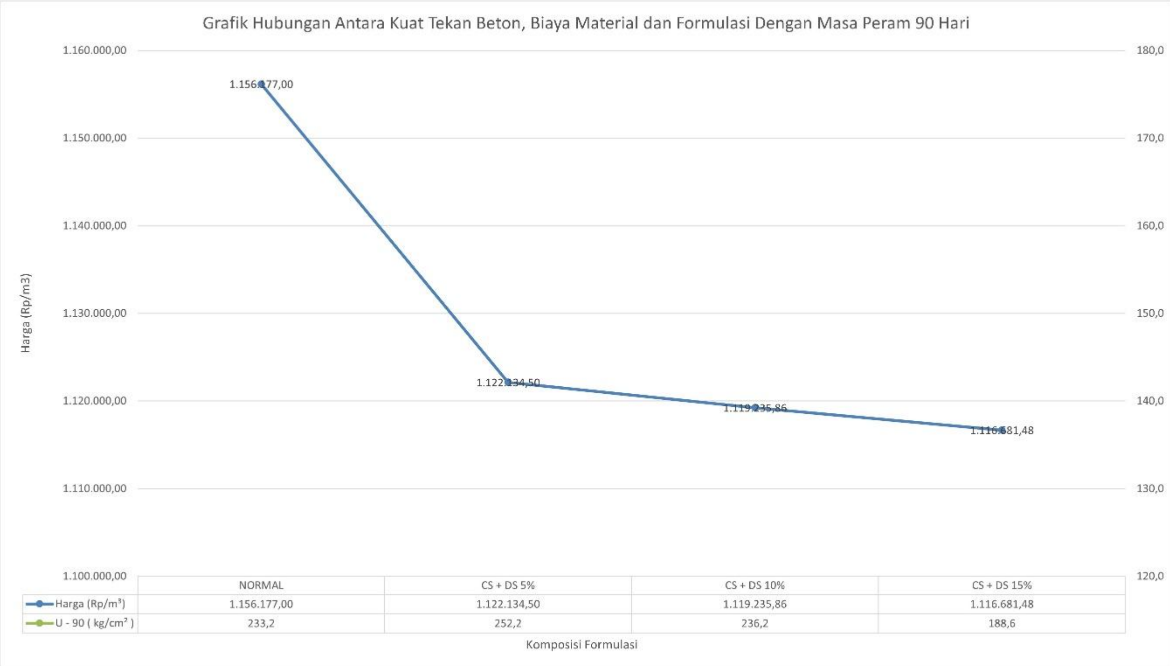

Figure 2. 90-Day Lifespan Strength Relationship Chart, Formulation and Cost

From figure 2 at the age of 90 days, The chart demonstrates the relationship between concrete compressive strength and material costs for different formulations over a 90-day curing period. Material costs, measured in Indonesian Rupiah per cubic meter, decrease as the percentage of additives (CS + DS) increases: from Rp 1,156,177.00 for the NORMAL formulation to Rp 1,116,681.48 for the CS + DS 15% formulation. However, unlike the 28-day cure period, the concrete compressive strength (U-90 kg/cm²) shows a less consistent trend; it initially rises from 233.2 kg/cm² in the NORMAL mix to a peak of 252.7 kg/cm² at 5% additives, then declines to 236.2 kg/cm² at 10%, and further decreases to 188.6 kg/cm² at 15%. This suggests that a 5% additive mix may improve strength slightly while still reducing costs, but higher additive percentages continue to reduce strength. The data thus highlights an important balance for optimizing both cost and concrete performance over the extended curing period according to project needs.

Utilization of *Carbon Sulfur* and *Dirty Sulfur Waste*

For waste utilization, it can be linked between compressive strength and cost. From the results of the compressive strength test, all formulations are determined when related to cost and utilization (materials used) can be seen in Figure 3 below.

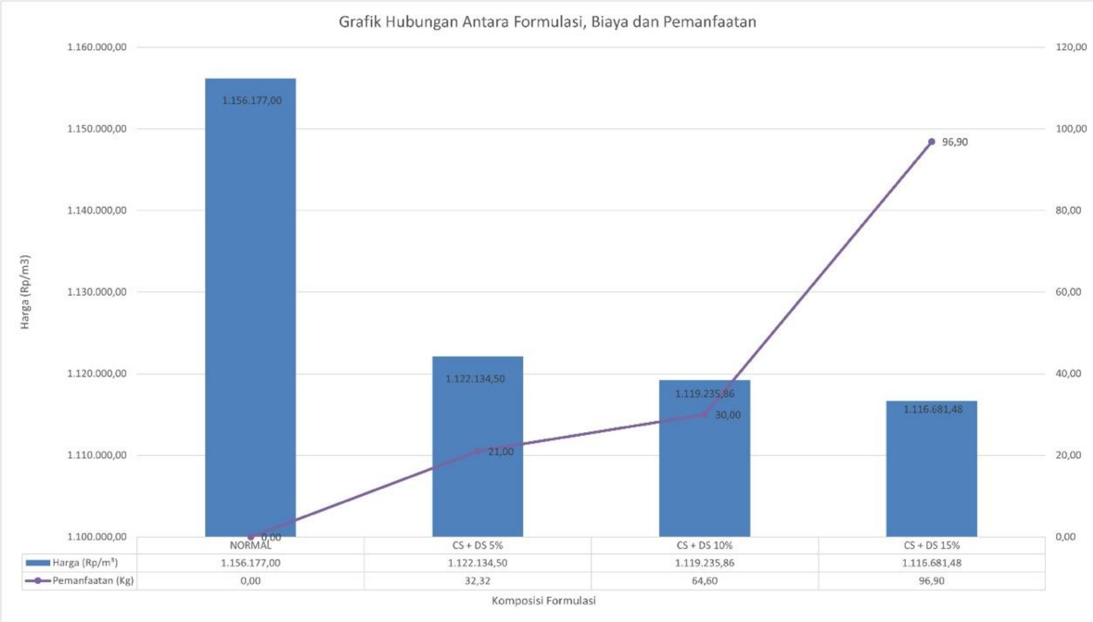

Figure 3. Graph of Formulation, Cost and Utilization Relationship

Figure 3 shows the relationship between cost and gramation of waste utilization. For the highest waste utilization, the 15% Cs+Ds formulation is 96.90 kg and is directly proportional to the cost incurred of IDR 1,116,681.48,-. The model of increasing the use of grammatical is directly proportional to the level of formulation set. The highest cost difference/normal and lowest concrete contained in the 15% Cs+Ds formulation is IDR 39,495,524,-. The graph of the relationship between compressive strength, formulation and utilization can be seen in figure 4 below.

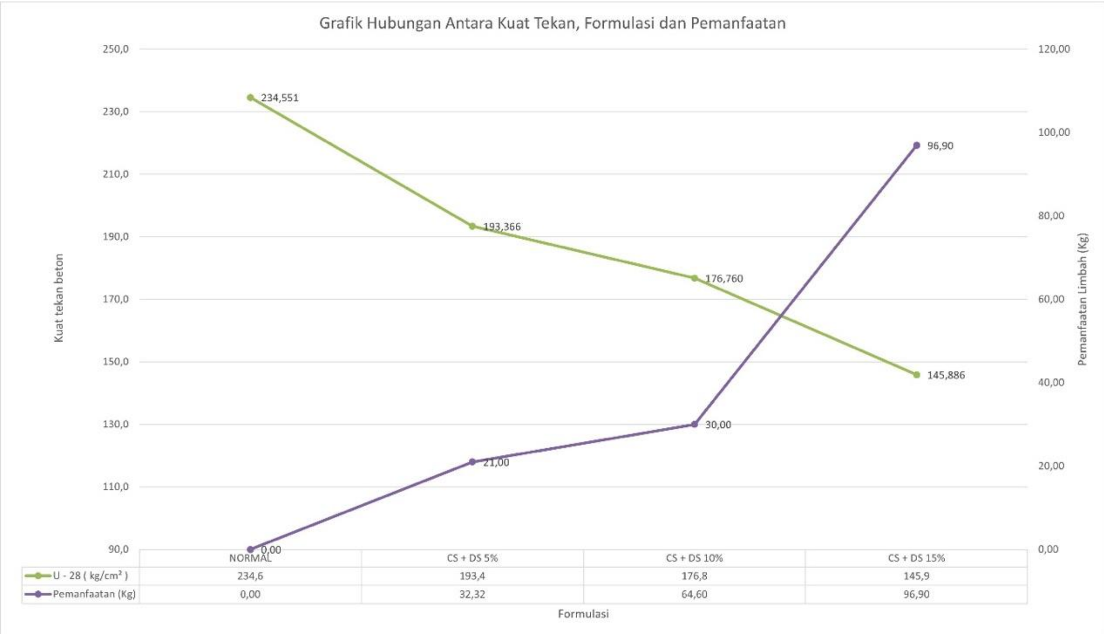

Figure 4. Graph of Strong Pressing, Formulation and utilization of U-28 Days

Figure 4 The chart illustrates the relationship between concrete compressive strength (U-28 in kg/cm²) and the utilization of waste materials (in kilograms) across four different concrete formulations: NORMAL, CS + DS 5%, CS + DS 10%, and CS + DS 15%. The data shows a clear inverse relationship where the compressive strength decreases as the percentage of additives increases, starting from 234.6 kg/cm² in the NORMAL mix and declining steadily to 145.9 kg/cm² at 15% additives. Conversely, the utilization of waste increases significantly with higher additive percentages, rising from 0 kg in the NORMAL formulation to 96.9 kg at the 15% additive level. This indicates that although increasing the additive content reduces the concrete's compressive strength, it plays an important role in enhancing waste utilization. The trade-off between strength and waste utilization is a key consideration for optimizing concrete formulations depending on project priorities.

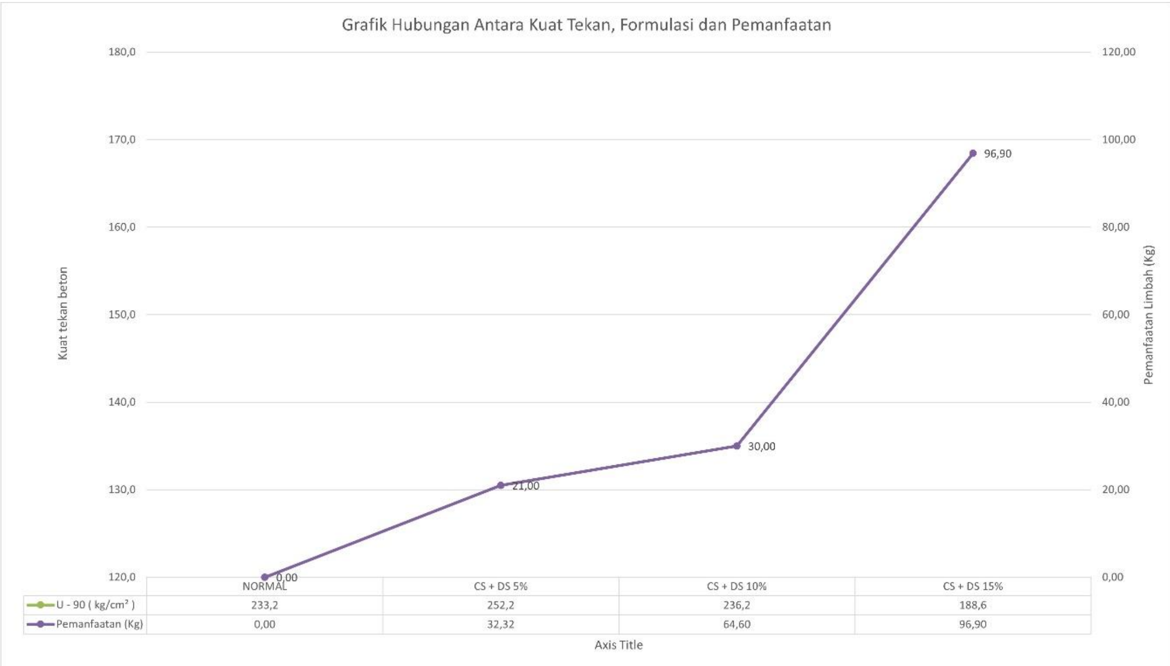

Figure 5. Graph of Strong Relationship Pressing, Formulation and Utilization of U-90 Days

Figure 5 shows the relationship between the utilization grammar and the compressive strength produced during the 90-day fermentation period. The highest gramation utilization was 96.90 kg with a compressive strength of 127.4 kg/cm². In the relationship between compressive strength and utilization gramation, it can be seen that the 10% Cs+Ds formula has the ideal grammation potential and compressive strength, which are 64.60 kg and 159.5 kg/cm².

28-Day Concrete Compressive Strength Analysis and Utilization Examples

From the results of the tests that have been carried out for the age of 28 days where all the results of the compressive strength obtained tend to increase compared to the beginning of the fermentation period, the highest and greater compressive strength than normal concrete is in the Cs 2% formulation which is 168.2 kg/cm² with a difference in compressive strength of 6.18% higher than normal concrete. In this phase, there is only 1 formulation that has the expected results. With this compressive strength result, the author will map based on the existing compressive strength if the formula that has been determined will be used as a concrete product according to their respective concrete grades. This analysis is expected to further enrich the mapping of each formulation if it will be used for several concrete products that are commonly used in the community.

The utilization distribution map is divided into 2 classes, namely class 1 and 2 concrete, where the class division is based on Code K, namely K 50, 100, 125, 150 and K 175. Where formulations that have been set with a 28-day fermentation period have many possibilities for use which are very useful for the community. The concrete products listed are very common in the market and easy to get.

Potential Utilization Model

The use of *carbon sulfur* waste and *dirty sulfur* is several materials for *civil engineering* purposes such as pavement, *paving blocks*, bricks, canteens, panel fence leaves, panel fence posts and *breakwater concrete.* The author tries to model if this solid waste material is used as rigid *pavement.* The definition of rigid pavement is as

A structure consisting of cement concrete slabs connected (non-continuously) with or without reinforcement, or continuous concrete slabs with reinforcement, which are located on the lower foundation layer, without or with asphalt as the surface layer. The dimensions of the pavement model are 1 km long, 8 m wide, and 40 cm thick as shown in the illustration of Figure 4.25 below.

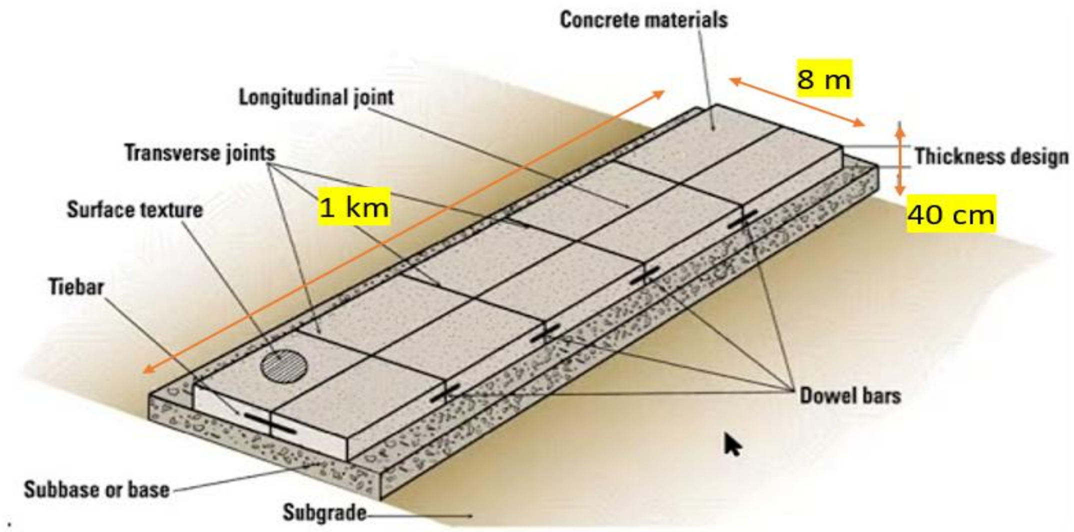

Figure 6. Illustration of Rigid Pavement Utilization Model
Dimensions *(1 Km x 8m x 40 cm)*

This rigid pavement criterion can also be used as a mining road or connecting road in PT. Vale Indonesia. The utilization of waste is closely related to the value of the rupiah to be issued, PT. Vale itself also has to spend a lot of money for the management of this solid waste, if this can be used as a positive thing related to the mobilization of their mining vehicles, of course this is a saving in production costs and the cost of transporting heavy equipment that they can get. In Table 4.27 below, the potential profits due to waste utilization and an illustration of the cost of rigid pavement per unit km.

Table 4. Cost Rigid Pavement Models Per Unit Km

Formula	Cost (Rp/m³)	Price of Rigid Pavement (1 KM x 8 M x 40 cm)	Potential Waste Absorbed (kg)
USUAL	**IDR1,156,177,00**	IDR 3,699,766,400,00	0
CS + DS 5%	IDR1,122,134,50	IDR 3,590,830,397.68	103.424
CS + DS 10%	IDR 1,119,235.86	IDR 3,581,554,747.38	206.720
CS + DS 15%	IDR 1,116,681.48	IDR 3,573,380,723,03	310.080

Source : Data Processing Results (2023)

From the results of data processing for waste utilization and related to the cost per unit m³ regardless of the compressive strength of concrete, it can be seen that the largest potential for waste to be absorbed is as much as 310,080 kg or 310 tons with a concrete manufacturing cost of IDR 3,573,380,723.03 in the Cs + Ds 15% formulation, with a potential cost savings of as much as IDR 126,385,676.97. The more solid waste is absorbed, directly proportional to the potential costs incurred. Of the 3 formulations that have been determined, if the greatest compressive strength value is taken during the 28 and 90-day fermentation periods, the but with a much less waste utilization potential than the 15% Cs + Ds formulation, which is 67.2 tons. Based on the comparison in Table 4.28, there are several alternative options that can be adjusted to 3 factors, namely cost, compressive strength and utilization depending on the user's side, namely PT. Vale Indonesia.

Economic Analysis of *Solid Waste Carbon Sulfur* and *Dirty Sulfur*

From the results of the calculation using the AHSP method, the difference in cost to the cost of normal concrete and the result of the addition of this solid waste was obtained. It can be seen in Table 5 below.

Table 5. Economic Value of Solid Waste *Carbon Sulfur dan Dirty Sulfur*

Formula	Cost (Rp/m³)	Difference (Rp/m³)
USUAL	**IDR1,156,177,00**	**IDR0,00**
CS + DS 5%	IDR1,122,134,50	IDR34,042,50
CS + DS 10%	IDR 1,119,235.86	IDR36,941.14
CS + DS 15%	IDR 1,116,681.48	IDR39,495.52

Source : 2023 Calculation Results

From the results of the calculation in Table 4.28, it can be seen that the formula that has the highest cost difference is the formula that uses this solid waste, namely the formula Cs + Ds 15% of Rp 39,495.52 which contains Cs Filler 18.3 kg, Cs Fine Aggregate 21 kg, Ds Filler 36.6 kg and Ds fine aggregate 21 kg. From the results of the calculation of the cost difference obtained, there is an economic value in the form of rupiah from the addition of this solid waste. The lowest economic value is in the Cs + DS 5% formulation which uses 7 32 kg Cs and DS with an economic value of as low as IDR 34,042. The result of this economic calculation is directly proportional to the amount of waste gramation mixed in each formulation.

Economic Potential of Carbon Sulfur and Dirty Sulfur Waste

To realize that *carbon sulfur and dirty sulfur* as part of raw materials as well as contributing to the circular economy, PT. Vale Indonesia needs to form a *carbon sulfur and dirty sulfur business unit*. The business unit or commercialization *of carbon sulfur and dirty sulfur* can be under the control of the "Sub Division" of Commercialization of Sulfur Waste. The establishment of the Sulfur Waste Commercialization Subdivision under is tasked with carrying out business, precisely selling as much and as quickly as possible *carbon sulfur and dirty sulfur* as raw materials that are suitable for creating added value. Thus, the unit formed is of course supported by human resources who are ready to collaborate with any business actor in the area around PT. Vale Indonesia, in particular, is close to the existence of *carbon sulfur and dirty sulfur storage*. Thus, the cooperation scheme that can be carried out is to establish business partners such as cement factories, state-owned infrastructure such as WIKA Beton, SMEs producing bricks, paving blocks and others with the selling price *of carbon sulfur and dirty sulfur* raw materials, of course, which must be cheaper than the raw materials that have been used by business actors (Non *carbon sulfur and dirty sulfur*). Advantages of PT. Vale Indonesia with the opportunity to sell *carbon sulfur and dirty sulfur,* especially after the issuance of regulations on the treatment of *carbon sulfur and dirty sulfur* which are categorized as Non B3 waste, it is expected to be able to sell *carbon sulfur and dirty sulfur* raw materials soon, so that the cost of managing *carbon sulfur and dirty sulfur* is gradually reduced. On the other hand, the *carbon sulfur and dirty sulfur* waste sold are also expected to increase. However, if in the short term it is not possible to create a subdivision for the commercialization *of carbon sulfur and dirty sulfur*, then it is necessary to create a task force in the unit that will be formed. Mining road maps and local roads around PT. Vale for 2022 and 2023 which has been planned by PT Vale Indonesia with the main goal of reducing waste costs (*cost reduction*) by the amount of waste treatment costs. The plan of PT. Vale Indonesia to immediately utilize *carbon sulfur and dirty sulfur* so that it can be fully commercialized, of course, requires more effective market planning and not just an "extra-curricular" program anymore but must be part of the success of PT. Vale Indonesia as a whole in providing nickel provider services for the wider community.

With the launch of a *roadmap* or plan to utilize *carbon sulfur and dirty sulfur* to fully profit in the following year, it takes experience in cooperation with business actors such as cement factories or others in utilizing *carbon sulfur and dirty sulfur*, of course they will be more ready to immediately declare *full profit*. *Fully profit* here means that there is a margin between the cost of transportation to the location and the value of the selling price of solid waste purchased by consumers. As for *cost sharing* or load sharing, this is certainly for coal-fired power plants outside the ones mentioned above that are not experienced in cooperation with business actors to take advantage of the existence of *carbon sulfur and dirty sulfur* with reduced storage/stockpiling costs per year of volume union. For example, cost *sharing* is the transportation burden financed by consumers or buyers of *carbon sulfur and dirty sulfur*, *carbon sulfur and dirty sulfur materials* free of charge or free of charge. But gradually, of course, the concept *of cost sharing* will be eliminated into a concept that generates *profits* at PT. Vale Indonesia

CONCLUSION

The results of the study show that solid waste of carbon sulfur and dirty sulfur has the potential to be used as an additive in concrete mixtures because the results of TCLP and *TK* laboratory tests do not exceed the category B waste threshold, with a loss on ignition value of less than 10%. Of the nine formulations tested and one normal concrete as a control, the three main formulations of Cs+Ds (5%, 10%, and 15%) were shown to be able to increase the compressive strength of concrete at curing ages of 7, 14, 28, 54, and 90 days, with the highest increases reaching 170.29 kg/cm², 179.40 kg/cm², and 127.39 kg/cm², respectively. In addition, all formulations produce lower concrete production costs than normal concrete, where the lowest cost is found at Cs+Ds 15% of *Rp* 1,116,681.48 per m³ with a difference of *Rp* 39,495.52. The higher the amount of waste added, the greater the volume of waste utilized, with the highest utilization potential in the 15% Cs+Ds formulation reaching 310,080 kg for 1 km of highway rigid pavement. The economic value of this waste utilization was recorded at *IDR* 34,042.50 (5%), *IDR* 36,941.14 (10%), and *IDR* 39,495.52 (15%). For further development, it is recommended to use this waste in class 1 and 2 concrete products such as tiles, paving blocks, concrete panels, and highways while still paying attention to work safety during the mix design; extend the curing period to 120 days; and encourage PT Vale Indonesia to develop a solid waste marketing sub-division to provide wider benefits to the environment and society, including advanced research for mass production scale.

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