



Upcycling used engine oil into stable water-based emulsions as sustainable concrete mold release agents

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ABSTRACT

This study presents a practical and scalable approach for converting hazardous used engine oil into a value-added material for construction applications, supporting resource circularity and more sustainable concrete manufacturing. A stable water-based oil-in-water (O/W) emulsion was developed using used engine oil as an environmentally friendly concrete mold release agent. The effects of surfactant type, mixed surfactant composition, and xanthan gum addition on emulsion stability were investigated through long-term storage tests and optical microscopy. Among the surfactants studied, the nonionic surfactant Dehydrol LS9 at 5 wt% showed the best performance, producing fine and uniformly dispersed oil droplets with good redispersibility after prolonged storage. The addition of 0.1 wt% xanthan gum further improved emulsion stability and adhesion to concrete mold surfaces, while the use of mixed surfactants did not significantly improve long-term stability. The optimized formulation was further evaluated under pilot-scale industrial conditions and could be uniformly sprayed onto concrete molds, providing effective demolding performance. Compared with conventional solvent-based products, the developed formulation also substantially reduced the use of organic solvents. This water-based formulation provides a low-cost and environmentally friendly alternative for concrete mold release applications, while improving worker safety and promoting the beneficial use of waste engine oil in sustainable construction.

Keywords: Used engine oil, water-based emulsion, circular economy, concrete demolding, sustainable construction

INTRODUCTION

The increasing demand for sustainable construction materials has driven the development of environmentally friendly alternatives to conventional concrete mold release agents (MRAs). MRAs are essential for preventing adhesion between fresh concrete and mold surfaces, thereby improving demolding efficiency, surface quality, and mold durability [1-3]. Conventional MRAs are commonly formulated from mineral oils or recycled lubricating oils diluted with organic solvents. Although these products provide effective lubrication at low cost, they release volatile organic compounds (VOCs) during application, posing environmental and occupational health risks. Moreover, the direct application of oil-based formulations often results in excessive oil consumption, non-uniform coating, and surface contamination of concrete products [4-5]. Consequently, water-based MRAs have attracted increasing attention because they reduce VOC emissions, improve sprayability, and provide more uniform coating while maintaining demolding performance.

Used engine oil is one of the largest hazardous wastes generated by the transportation and manufacturing industries. The improper disposal of used engine oil can contaminate soil and water because it contains degraded hydrocarbons, oxidation products, heavy metals, and other hazardous compounds [6-7]. Although conventional recycling technologies, such as re-refining and energy recovery, are available, they require substantial energy input and capital investment. Therefore, developing value-added applications for used engine oil represents an attractive strategy for waste valorization and supports the principles of circular economy [8-12]. Converting used engine oil into stable oil-in-water (O/W) emulsions is a promising approach for producing sustainable water-based MRAs while reducing the consumption of organic solvents [13-14]. Fine oil droplets are dispersed in a continuous aqueous phase in O/W emulsions and stabilized by surfactants that reduce interfacial tension and suppress droplet coalescence [15-17]. However,

the stability of used engine oil emulsions is strongly influenced by surfactant chemistry, concentration, and composition. Insufficient emulsion stability results in droplet aggregation, phase separation, and poor storage performance, thereby limiting practical applications. Increasing the viscosity of the continuous phase using hydrocolloids, such as xanthan gum, improves emulsion stability and enhances adhesion to vertical surfaces [18–19]. Although mixed surfactant systems may provide synergistic stabilization in some emulsion systems, their effectiveness for used engine oil-used concrete MRAs remains unclear.

Despite the widespread use of recycled lubricating oil as a low-cost mold release agent, the development of stable water-based emulsions directly from used engine oil remains limited, particularly for formulations validated under practical industrial conditions. Previous oil-in-water (O/W) emulsion-based release agents have generally involved high-viscosity formulations, multiple surfactants, and additional dilution with water prior to spraying, which may complicate preparation and practical application. To address these limitations, this study introduces a simple, stable, and ready-to-spray water-based concrete mold release agent produced by upcycling used engine oil into an O/W emulsion. The effects of surfactant type, mixed-surfactant composition, and xanthan gum addition on emulsion stability were systematically investigated through long-term storage evaluation and optical microscopy. Importantly, the optimized formulation was directly applied without further dilution and validated in pilot-scale industrial concrete demolding trials, demonstrating effective sprayability and practical demolding performance. The novelty of this work therefore lies in integrating waste-oil upcycling with a simplified, readily applicable emulsion formulation and pilot-scale validation, providing a cost-effective and scalable route for converting hazardous used engine oil into a value-added construction chemical while reducing organic solvent consumption and promoting resource circularity.

MATERIALS AND METHODS

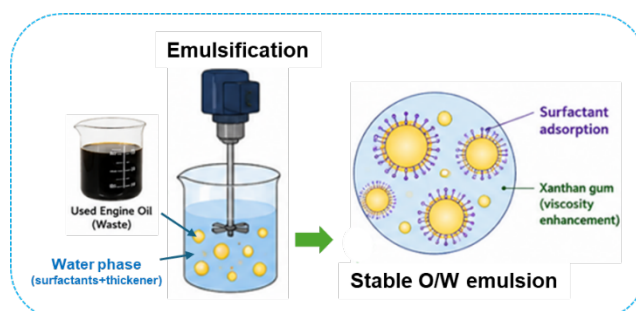
Materials

The used engine oil (viscosity 148 cP) was supplied by Rico Construction Co., Ltd. (Thailand). The oil was filtered to remove coarse solid impurities before use and stored in sealed containers at ambient temperature. Commercial surfactants, e.g., Dehydol LS7 (lauryl alcohol ethoxylate, Thai Ethoxylate, CMC 0.035–0.045 g/L), Dehydol LS9 (lauryl alcohol ethoxylate, Thai Ethoxylate, CMC 0.041–0.058 g/L), Eumulgin O5 (oleyl alcohol ethoxylate, BASF, CMC not available), Eumulgin LM23 (laureth-23, BASF, CMC 0.108 g/L), Tween 20 (Guangdong Runhua Chemistry, CMC 0.074 g/L), Tween 80 (ACROS, CMC 0.016 g/L), Dehyquart A-CA (cetrimonium chloride/laurtrimonium chloride,

BASF CMC 0.416 and 5.28 g/L, respectively), Dehyton K/I5 (cocamidopropyl betaine, BASF, CMC 0.031 g/L), and sodium dodecyl sulfate (SDS, Carlo Erba, CMC 2.36 g/L) were investigated. Xanthan gum (CP Kelco), a thickening agent, was also used. All chemicals were used as received without further purification.

Preparation of water-based used engine oil emulsions

Water-based oil-in-water (O/W) emulsions were prepared using a high-shear homogenization process, as illustrated in Scheme 1. The overall preparation conditions, including the effects of surfactant types, mixed-surfactant composition, and addition of thickening agent, was optimized, as detailed in Table 1.



Scheme 1 Summary of the fabrication of a water-based oil-in-water (O/W) emulsion from used engine oil.

In the preliminary study, experiments were conducted using surfactant concentration ranging from 1 to 5 w%, calculated base on the mass of the aqueous phase. At concentrations below 5 wt%, the resulting emulsions and oil droplets were less uniform and more rapid phase separation. Therefore, a surfactant concentration of 5 wt% was selected to improve emulsion formation and stability. The surfactant was completely dissolved in the water. Subsequently, the aqueous solution was mixed with used engine oil at an oil-to-water mass ratio of 3:10. The mixture was homogenized using a high-speed homogenizer (IKA, T25) at 5,000 rpm for 5 min. After homogenization, the emulsions were transferred into sealed glass bottles and stored at room temperature for further stability evaluation. The effects of surfactant type on emulsion formation and stability were systematically investigated.

Mixed-surfactant formulations consisting of non-ionic Dehydol LS9 and anionic SDS were investigated to further enhance colloidal stability. Dehydol LS9 and SDS were blended at weight ratios of 50:50, 70:30, and 90:10, respectively, while maintaining the total surfactant concentration at 5 wt%. Subsequently, the aqueous phase was mixed with used engine oil at an oil-to-water ratio of 3:10, followed by homogenization at 10,000 rpm for 10 min. Subsequently, the influence of surfactant composition on emulsion stability was evaluated.

Table 1 Summary on preparation conditions of water-based used engine oil emulsions at an oil-to-water ratio of 3:10.

Formulation	Oil phase		Water phase			Homogenization conditions
	Used oil (g)	Surfactant (g)	SDS (g)	Xanthan gum (g)	Water (g)	
<i>Effect of surfactant types</i>						
Dehydol LS7	30	5	-	-	95	5,000 rpm, 5 min
Dehydol LS9	30	5	-	-	95	
Eumulgin O5	30	5	-	-	95	
Eumulgin LM23	30	5	-	-	95	
Tween 20	30	5	-	-	95	
Tween 80	30	5	-	-	95	
Dehyquart A-CA	30	5	-	-	95	
Dehyton K/I5	30	5	-	-	95	
<i>Mixed surfactant formulations</i>						
Dehydol LS9/SDS – 50:50	30	2.5	2.5	-	95	10,000 rpm, 10 min
Dehydol LS9/SDS – 70:30	30	3.5	1.5	-	95	
Dehydol LS9/SDS – 90:10	30	4.5	0.5	-	95	
<i>The addition of thicken agent</i>						
XG 0	30	5	-	0	95	10,000 rpm, 10 min
XG 0.1	30	5	-	0.1	94.9	
XG 0.2	30	5	-	0.2	94.8	
XG 0.5	30	5	-	0.5	94.5	
XG 1.0	30	5	-	1.0	94.0	

The morphology and dispersion of oil droplets were examined using an optical microscope (OM; OPTIKA ITALY, B-192PL). A small amount of emulsion was placed on a glass microscope slide and covered with a cover slip before observation. Micrographs were collected to compare the droplet size distribution and dispersion uniformity among different formulations. Average particle diameter and size distribution were analyzed using ImageJ processing software (n=100).

The prepared emulsions' physical stability was evaluated by visual observation during storage at ambient temperature. The samples were monitored after 1, 3, 7 days, as well as after 1–4 months, to determine the phase separation, creaming, sedimentation, and re-dispersibility. After prolonged storage, the separated samples were gently shaken by hand to evaluate their ability to redisperse into homogeneous emulsions. The re-dispersibility of the emulsions was considered an important practical parameter for transportation and industrial storage.

Concrete mold release performance

The developed emulsions' practical performance was evaluated using industrial concrete molds supplied by Rico Construction Co., Ltd. The emulsions were

uniformly sprayed onto the mold surfaces before concrete casting. After curing, the concrete specimens were demolded and visually inspected for surface quality, ease of mold release, and the presence of surface defects. Both indoor and outdoor casting conditions were investigated to assess the effect of environmental exposure on coating performance.

RESULTS AND DISCUSSION

Effect of surfactant type on the formation and stability of engine oil emulsions

The selection of an appropriate surfactant is one of the most critical factors governing the formation and long-term stability of O/W emulsions. Stabilizing these heterogeneous oil droplets in an aqueous medium is considerably more challenging than emulsifying fresh mineral oils because used engine oil contains a complex mixture of hydrocarbons, oxidation products, degraded lubricant additives, and fine particulate contaminants. Eight commercially available surfactants representing different chemical classes, including non-ionic, cationic, and amphoteric, were investigated to identify suitable emulsifiers. The prepared emulsions were stored at room temperature for up to 4 months before their

stability was evaluated using visual observation and optical microscopy. The results are shown in Figure 1.

All formulations appeared as grayish-brown emulsions after homogenization, indicating successful dispersion of oil droplets within the continuous aqueous phase. However, differences in storage stability became increasingly obvious with prolonged storage. Most formulations gradually exhibited gravitational phase separation caused by creaming and droplet coalescence (Figure 1A). Such instability is expected because the dispersed oil droplets tend to migrate upward owing to density differences between the oil and aqueous phases. At the same time, insufficient interfacial protection accelerates droplet collision and coalescence.

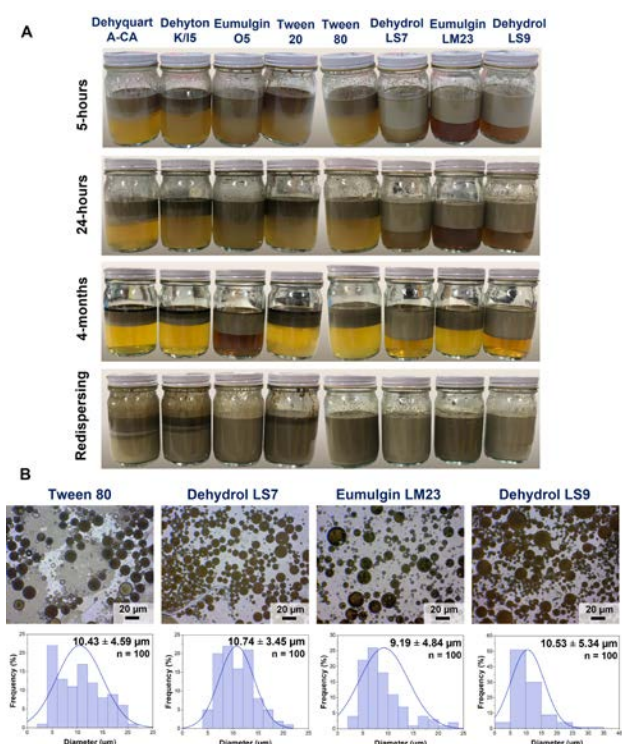


Figure 1 (A) Visual appearance of the prepared emulsions after different storage times, (B) Optical microscopy images and size distribution of the representative emulsions.

The emulsions prepared using cationic (Dehyquart A-CA), amphoteric (Dehyton K/I5), or non-ionic surfactants (Tween 20 and Eumulgin O5) showed poor re-dispersibility after storage, suggesting stronger droplet aggregation and irreversible coalescence. In contrast, emulsions stabilized with non-ionic surfactants, such as Dehydrol LS9, Dehydrol LS7, Eumulgin LM23, and Tween 80, exhibited noticeably superior storage stability. Although partial phase separation was observed after 4 months, these emulsions were readily restored to homogeneous systems by gentle manual shaking, indicating reversible physical separation rather than irreversible emulsion breakdown. The excellent performance of the alcohol ethoxylate surfactants can be attributed to their balanced hydrophilic-lipophilic properties and their ability to efficiently adsorb at

the oil-water interface. Their poly(ethylene oxide) chains generate a hydrated steric barrier surrounding each oil droplet, preventing close droplet contact and suppressing coalescence during storage [13, 20–21]. Furthermore, these non-ionic surfactants exhibit relatively low sensitivity toward dissolved electrolytes and contaminants commonly present in used engine oil, making them particularly suitable for stabilizing recycled lubricant emulsions. The droplet dispersion observed by optical microscopy correlated well with the enhanced storage stability obtained from visual observations (Figure 1B). The oil droplets were uniformly dispersed throughout the aqueous phase, with an average droplet diameter of approximately 10 μm. The uniform and small size reflected the greater availability of surfactant molecules capable of rapidly adsorbing onto newly generated interfaces during high-shear homogenization [22]. Complete interfacial coverage suppresses droplet coalescence immediately after droplet formation, thereby producing fine emulsions with greater kinetic stability.

Industrially, an important characteristic of the developed emulsions is their ability to rapidly redispense after storage [23]. Since concrete mold release agents are typically stored and transported before use, complete resistance to phase separation is less critical than maintaining rapid re-dispersibility without permanent aggregation. Therefore, the present results demonstrate that Dehydrol LS9 possesses the greatest potential for developing commercially viable water-based mold release formulations.

To enhance emulsion stability, the processing parameters, including surfactant type and concentration, homogenization speed and time were optimized. The mixing speed and time were adjusted to 10,000 rpm and 10 min, respectively, to promote efficient droplet breakup and improve droplet uniformity. Under these conditions, the resulting emulsion was more homogenous with no phase separation for 24 h. Therefore, these homogenization conditions were applied in the subsequent experiment.

Effect of mixed surfactants on colloidal stability

Although Dehydrol LS9 exhibited excellent emulsifying capability, the complete suppression of phase separation during prolonged storage remained challenging. Therefore, mixed surfactant systems consisting of the non-ionic surfactant Dehydrol LS9 and the anionic surfactant SDS were investigated at various Dehydrol LS9:SDS ratios (50:50, 70:30, and 90:10). The rationale was that mixed surfactant systems often exhibit synergistic effects because different surfactant molecules can pack more efficiently at the oil–water interface than a single surfactant. Dehydrol LS9 primarily provides steric stabilization through its hydrated ethylene oxide chains, whereas SDS contributes to electrostatic stabilization via negatively charged sulfate groups [14]. The combination of steric hindrance

and electrostatic repulsion is expected to increase the energy barrier against droplet coalescence, thereby enhancing emulsion stability.

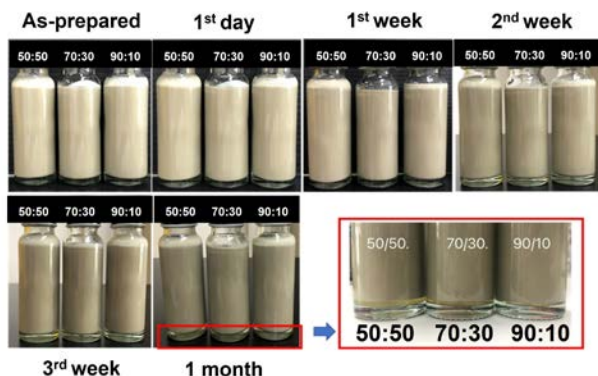


Figure 2 Appearance of Dehydol LS9/SDS emulsions after storage for various times.

However, all formulations initially appeared as homogeneous milky emulsions immediately after preparation, as shown in Figure 2. After 1 week of storage, the emulsions gradually changed to a light brown color, which further intensified to dark brown after 1 month. Moreover, visible phase separation was observed in all formulations, indicating progressive emulsion destabilization. This color change and phase separation are likely associated with droplet coalescence and subsequent oil phase separation during storage. These results demonstrated that despite the anticipated synergistic stabilization from the combined steric and electrostatic mechanisms, the Dehydol LS9/SDS mixed surfactant systems were still insufficient to provide satisfactory long-term stability for the recycled oil emulsions.

Influence of thickening agent on emulsion stability and concrete mold adhesion

To overcome this limitation, xanthan gum was introduced as a rheological modifier. Xanthan gum is widely employed as a natural thickening agent because of its excellent water solubility, high viscosity at low concentrations, and outstanding stability over broad pH and temperature ranges. The incorporation of xanthan gum significantly increased the viscosity of the continuous aqueous phase, thereby reducing droplet mobility and suppressing creaming, as shown in Figure 3A. The emulsions containing > 0.2 wt% xanthan gum exhibited excellent storage stability, remaining homogeneous without observable phase separation after storage at room temperature for 1 month.

For preliminary sprayability evaluation, the emulsion containing 1.0 wt% xanthan gum could not be applied using a manual laboratory spray bottle because of its excessively high viscosity. Therefore, emulsions containing 0.1 - 0.5 wt% xanthan gum were selected for further sprayability tests. The emulsions were spray-applied onto vertically positioned steel plates,

and their wetting behavior and flow characteristics were monitored at different standing times, as shown in Figure 3B. Compared with the emulsion without xanthan gum, the addition of xanthan gum markedly improved the emulsion's wettability and retention on the steel surface. At xanthan gum concentrations of 0.2 and 0.5 wt%, a continuous oil film remained on the steel plate even after 75 min of exposure, indicating enhanced film-forming ability and resistance to gravitational flow. The increased viscosity imparted by xanthan gum effectively improved the adhesion of the emulsion to vertical mold surfaces, enabling the lubricating film to remain attached for a longer period before concrete casting. This enhanced retention is particularly beneficial for outdoor construction applications, where delays between spray application and concrete placement are common.

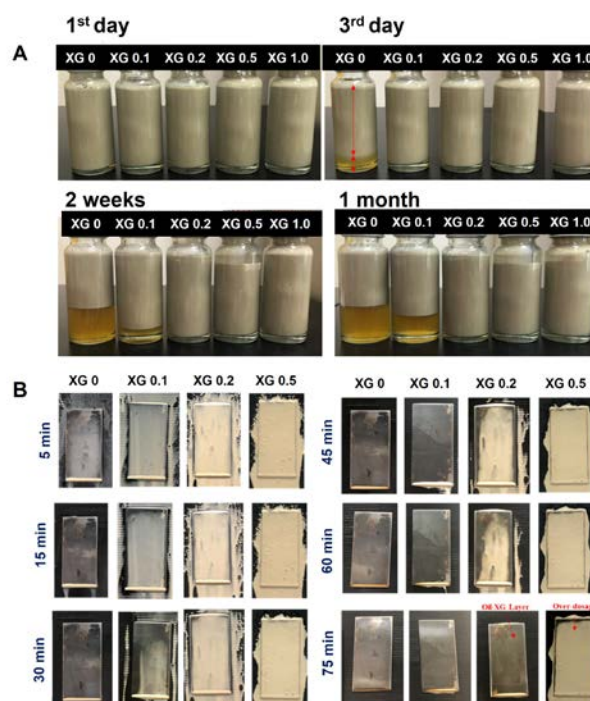


Figure 3 (A) Visual appearance of emulsions prepared with different xanthan gum concentrations (0-1.0 wt%). (B) Photographs of the steel plate surfaces after spraying the emulsions for different durations.

From a colloidal perspective, increasing continuous-phase viscosity decreases droplet sedimentation and creaming rates while simultaneously reducing collision frequency between neighboring droplets. Consequently, droplet coalescence is less likely during storage. In addition, xanthan gum contributes to the formation of a more continuous lubricating film after spraying, thereby improving surface coverage and reducing premature evaporation of water under outdoor conditions. These improvements are particularly important for large-scale construction sites where spraying and concrete pouring are often separated by relatively long time intervals. Therefore,

the addition of xanthan gum provides a practical solution that enhances formulation stability and field applicability.

Considering emulsion stability, sprayability, surface retention, mold-release performance, and formulation cost, 0.1 wt% xanthan gum was selected as the optimized concentration. This minimum effective concentration provided satisfactory practical performance while avoiding excessive thickening, substantial residue after casting, and unnecessary additive consumption.

Industrial evaluation of concrete mold release performance

The optimized formulation (5.0 wt% dehydrol LS9 + 0.1 wt% xanthan gum) was subsequently evaluated under practical industrial conditions by Rico Construction Co., Ltd. Approximately 20 L of emulsion was prepared and tested on actual concrete molds under both indoor and outdoor construction environments. Figure 4 shows the spray application onto steel molds for outdoor casting.



Figure 4 (A) Spray application onto steel molds for outdoor casting and (B) demolded concrete surfaces.

Under indoor conditions, the developed water-based emulsion produced uniform coating coverage and facilitated smooth mold removal without noticeable adhesion between the concrete and mold surface. The resulting concrete exhibited smooth

surfaces with minimal defects, indicating that the emulsion effectively reduced interfacial bonding during curing. In contrast, outdoor testing, as seen in Figure 4, demonstrated greater challenges due to elevated ambient temperature, wind, and solar radiation. After spraying, water evaporation occurred more rapidly, leading to premature drying of the lubricating film before concrete casting. Consequently, maintaining continuous surface coverage became more difficult. This observation further highlights the importance of optimizing the viscosity and water retention characteristics for field applications.

The proposed mechanism is illustrated in Figure 5. The stabilization mechanism involves the adsorption of surfactant molecules onto the oil-water interface, resulting in steric stabilization that prevents droplet coalescence. Xanthan gum increases the viscosity of the continuous phase, thereby reducing droplet mobility and prolonging storage stability. During spraying, the emulsion forms a thin, continuous lubricating layer that minimizes direct contact between the cement paste and the steel mold. As hydration proceeds, this lubricating film remains sufficiently stable to reduce interfacial adhesion while allowing clean mold separation after curing. The action of the developed engine oil emulsion.

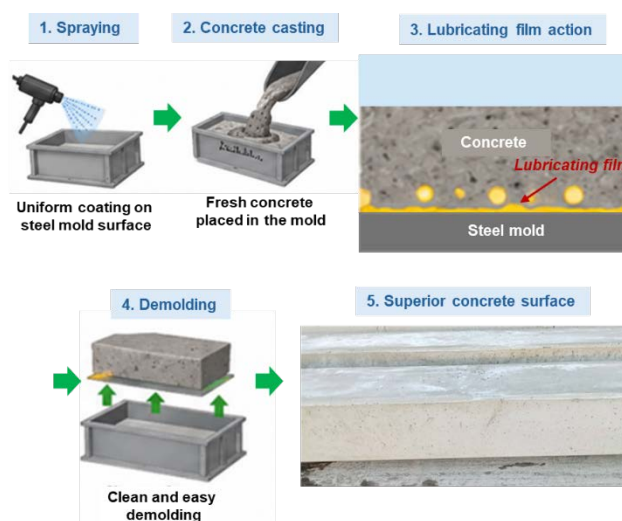


Figure 5 Proposed mechanism illustrating the action of the developed water-based used engine oil emulsion.

Pilot-scale testing demonstrated that the optimized formulation could be uniformly spray-applied onto steel molds, producing smooth concrete surfaces after demolding. Compared with the company's conventional solvent-diluted formulation, the developed water-based emulsion substantially reduced organic solvent consumption while maintaining effective mold release performance. The uniform spray application also minimized excessive lubricant usage, thereby reducing residual oil contamination

on the finished concrete surfaces. Similarly, water-based emulsions improve application efficiency and concrete surface quality compared with conventional oil-based products.

CONCLUSIONS

A sustainable water-based concrete mold release agent has been successfully developed by upcycling used engine oil into stable oil-in-water emulsions, offering an environmentally friendly alternative to conventional solvent-based products. Among the investigated surfactants, non-ionic Dehydol LS9 provided the best emulsification performance, droplet dispersion, and storage stability. The addition of xanthan gum enhanced viscosity and adhesion to vertical mold surfaces, thereby delaying premature drying during spraying.

Industrial-scale validation demonstrated that the optimized formulation could be readily spray-applied, enabling efficient concrete demolding and producing smooth concrete surfaces with minimal defects. The developed emulsion reduces organic solvent consumption, improves worker safety, and lowers environmental impact while maintaining practical performance compared with conventional solvent-diluted release agents.

DECLARATION OF AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

The authors utilized Open AI's ChatGPT to improve the readability and clarity of the text during the preparation of this work. The authors reviewed and edited the content as needed and take full responsibility for the content of the publication after using this tool/service.

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REFERENCES

1. Barnat-Hunek D, Szafraniec M. Influence of Biodegradable Release Oils on the Physical and Mechanical Properties of Light-Colored Architectural Concrete. *Materials*. 2021;14(16):4630.
2. Liang B, Yang Y, Li J. Research progress of water-based release agents. *MATEC Web Conf.* 2022;358.
3. Yang M, Li L, Zhu Z, Ma H. Research progress on eco-friendly rubber release agents. *Colloid Polym Sci.* 2025;303(2):163-74.
4. Olietti A, Pargoletti E, Diona A, Cappelletti G. A novel optimized mold release oil-in-water emulsion for polyurethane foams production. *J Mol Liq.* 2018;261:199-207.
5. Scrivener KL, John VM, Gartner EM. Eco-efficient cements: Potential economically viable solutions for a low-CO₂ cement-based materials industry. *Cement Concrete Res.* 2018;114:2-26.
6. Moses KK, Aliyu A, Hamza A, Mohammed-Dabo IA. Recycling of waste lubricating oil: A review of the recycling technologies with a focus on catalytic cracking, techno-economic and life cycle assessments. *J Environ Chem Eng.* 2023;11(6):111273.
7. Rongsayamanont W, Tongcumpou C, Phasukarratchai N. Diesel-Contaminated Soil Washing by Mixed Nonionic Surfactant Emulsion and Seed Germination Test. *Water Air Soil Pollut.* 2020;231(6):267.
8. Mishra A, Mishra NS. Sustainable Utilization of Waste Motor Oil: A Hazardous Hydrocarbon Pollutant. In: Behera ID, Das AP, editors. *Environmental Hydrocarbon Pollution and Zero Waste Approach Towards a Sustainable Waste Management*. Cham: Springer Nature Switzerland; 2025. p. 241-53.
9. García-Gutiérrez P, Tonini D, Klenert D, Marschinski R, Saveyn HGM. Environmental and economic assessment of waste lubricant oil management in the EU. *J Clean Prod.* 2025;492:144878.
10. Islam Sazzad MR, Rahman MM, Hassan T, Al Rifat A, Al Mamun A, Adib AR, et al. Advancing sustainable lubricating oil management: Re-refining techniques, market insights, innovative enhancements, and conversion to fuel. *Heliyon.* 2024;10(20):e39248.
11. Kanokkantapong V, Kiatkittipong W, Panyapinyopol B, Wongsuchoto P, Pavasant P. Used lubricating oil management options based on life cycle thinking. *Resour Conserv Recy.* 2009;53(5):294-299.
12. Cabrera-Escobar C, Moreno-Gutiérrez J, Rodríguez-Moreno R, Pájaro-Velázquez E, Calderay-Cayetano F, Durán-Grados V. A Review on Global Recovery Policy of Used Lubricating Oils and Their Effects on the Environment and Circular Economy. *Environments.* 2025;12(5):135.
13. Abbas A, Zhang C, Hu G, Hussain S, Gao R, Li J, et al. Facile formulation of sustainable and stable oil-in-dispersion emulsion: A release agent with high demoulding efficacy. *Chem Eng J Adv.* 2022;12:100394.
14. Abbas A, Zhang C, Hussain S, Tang Y, Li Y, Gao R, et al. Preparation of ultrastable oil-in-water emulsion as a robust superwetable and sustainable concrete release agent. *J Mol Liq.* 2023;390:123043.

15. Tadros TF. Emulsion Formation and Stability. Wiley-VCH; 2013.
16. Peng L-C, Liu C-H, Kwan C-C, Huang K-F. Optimization of water-in-oil nanoemulsions by mixed surfactants. *Colloid Surface A*. 2010;370(1):136-42.
17. Rosen MJ, Kunjappu JT. Surfactants and Interfacial Phenomena. 4th e d. John Wiley & Sons; 2012.
18. Nsengiyumva EM, Alexandridis P. Xanthan gum in aqueous solutions: Fundamentals and applications. *Int J Biol Macromol*. 2022;216:583-604.
19. Zhang J, Tai X, Liu H, Ma X, Gao X, Luo Y. Effect of xanthan gum on stability and rheological behavior of O/W emulsion. *J Disper Sci Technol*. 2025;46(14): 2189-97.
20. Holmberg K. Natural surfactants. *Cur Opin Colloid In*. 2001;6(2):148-59.
21. McClements DJ. Emulsion Design to Improve the Delivery of Functional Lipophilic Components. *Annu Rev Food Sci T*. 2010;1:241-69.
22. McClements DJ. Nanoemulsions versus microemulsions: terminology, differences, and similarities. *Soft Matter*. 2012;8(6):1719-29.
23. Jafari SM, Assadpoor E, He Y, Bhandari B. Re-coalescence of emulsion droplets during high-energy emulsification. *Food Hydrocolloid*. 2008;22(7):1191-202.