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SYSTEM DESIGN AND PROTOTYPE MANUFACTURING FOR THE RECOVERY OF LUBRICANT POWDER USED IN WIRE DRAWING PROCESS

TEL ÇEKME PROSESLERINDE KULLANILAN TOZ SABUNUN GERI KAZANIMI İÇIN SISTEM TASARIMI VE PROTOTIP İMALATI

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ABSTRACT

Recycling processes have gained great importance for both environmental and economic sustainability and development. A prototype system was developed using physical separations including size sieving and magnetic separation for the recycling of solid die soaps used as lubricants in industrial wire drawing processes. The chemical composition of the waste obtained after the wire drawing process was elucidated by using X-ray fluorescence (XRF) analysis and extraction methods. The results showed that there was 67% reusable soap in the waste, and most of the remaining waste was made up of metals. Parameters such as particle size, sieve pore diameters, shaking time and magnetic field strength were optimized and an industrial scale prototype recycling system was designed. Finally, a prototype recovery system was established. Scanning electron microscopy (SEM), light microscopy, thermogravimetric/differential thermal analyzes (TGA/DTA), X-ray fluorescence spectroscopy (XRF) and Fourier transform infrared spectroscopy (FTIR) were used for the characterization. 88% of the soap in the waste was recovered, and the soap obtained was successfully used in wire drawing process without causing any deformation in the wire. These findings clearly demonstrate that offered system design engineered solution has a great potential to become a way out point for the waste recycling gain in the recovery and reuse of lubricant powder.

Keywords: Wire drawing, reduction, die soap, recovery

ÖZET

Günümüzde geri dönüşüm süreçleri hem çevresel hem de ekonomik sürdürülebilirlik ve kalkınma için büyük önem kazanmıştır. Bu çalışmada, endüstriyel tel çekme işlemlerinde yağlayıcı olarak kullanılan katı kalıp sabunlarının geri dönüşümü için eleme ve manyetik ayırmayı içeren fiziksel yöntemler kullanılarak yeni bir yöntem ve prototip sistem geliştirilmiştir. Tel çekme işlemi sonrasında elde edilen atığın kimyasal bileşimi X-ray floresan (XRF) analizi ve ekstraksiyon yöntemleri kullanılarak görülmüştür. Elde edilen sonuçlar, atıkta %67 oranında yeniden kullanılabilir sabun bulunduğunu ve kalan atığın çoğunun metallerden oluştuğunu göstermiştir. Geri dönüşüm için partikül boyutu, elek gözenek çapları, sallama süresi ve manyetik alan gücü gibi parametreler optimize edilmiş olup optimum koşullar kullanılarak endüstriyel ölçekli bir prototip geri dönüşüm sistemi tasarlanmıştır. Son olarak optimum koşulları içeren bu veriler ışığında bir prototip kurtarma sistemi kurulmuştur. Bu çalışmada, analizler için elektron mikroskobu (SEM), ışık mikroskobu, termogravimetrik/diferansiyel termal analizler (TGA/DTA), X-ışını floresan spektroskopisi (XRF) ve fourier transform kızılötesi spektroskopisi (FTIR) kullanılmıştır. Sonuçlar, atıktaki sabunun %88' inin geri

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kazanıldığını ve elde edilen sabunun telde herhangi bir deformasyona neden olmadan tel çekme işleminde başarıyla kullanıldığını göstermiştir. Bulgular, önerilen sistem tasarımı çözümünün, yağlayıcı tozun geri kazanılması ve yeniden kullanılmasında atık geri dönüşümü kazanımı için bir çıkış noktası olma konusunda büyük bir potansiyele sahip olduğunu açıkça göstermektedir.

Anahtar Kelimeler: Tel çekme, redüksiyon, hadde sabunu, geri kazanım

INTRODUCTION

Wire drawing is a process that pulls the rod manufactured in the line rolling process through a die with a hole by means of an applying tensile force to the exit side. The end product of this process is called wire. In industrial manner, these are used for many different purposes. Wires having 3 mm-50 µm of diameter are usually used for making wire ropes and defined as thin wire. The wires having 3 mm-40 mm of diameter are used for manufacturing bolt and fastener through a cold heading process and defined as thin wire (Kim et al., 2014; Byon et al., 2011). Lubrication is the most important determining parameter for high productivity in cold heading. Therefore, the lubricating strategy adopted must be defined in the product design phase just at the beginning. The geometry of the product, customer request details, the materials need, etc. are all factors that effects the lubricating systems options. After defining the lubricating strategy, the performance level will be easily maintained to ensure a regular process. During the wire drawing process, the friction force that occurs as a result of the metal-metal contact during the winding of the wires through the die to the wire drawing machine blocks creates a resistance in the process (Gustavo et al., 2020; Andre et al., 2001). The friction force creates a resistance, releases high heat, deteriorates the wire quality, shortens the life of the mold and causes excessive energy consumption (Moon and Kim, 2012). Lubricating soaps are used to reduce this resistance and facilitate shrinkage. In this regard, different soap solutions are being researched recently (Hu et al., 2023; Wu et al., 2023; Jeiman et al., 2023; Sarma and Vinu, 2022; Donato et al., 2021; Xu et al., 2020).

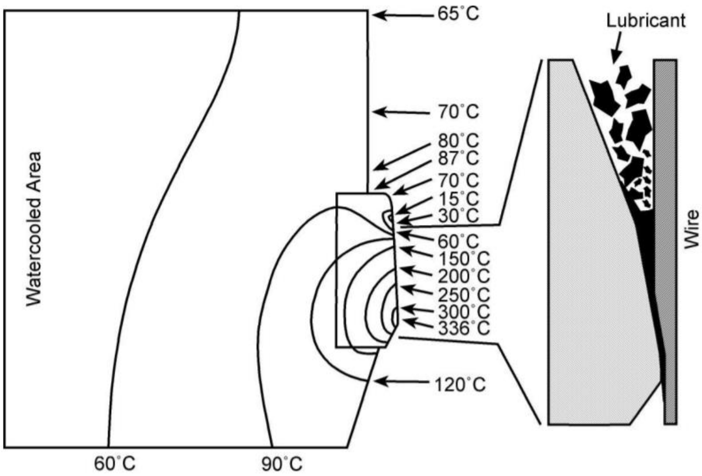

Fig. 1. Shows the Wire Drawing Process Using Solid Lubricant and the Resulting Temperatures (Dove et al., 1980)

Wire drawing lubricants show distinctness according to the using processes. They are basically divided into two as solid and liquid lubricants (Masao et al., 2004). Liquid lubricants are generally used during the reduction (diameter reduction) process of copper wires. Solid lubricants are divided into three as calcium, sodium and aluminum stearate soaps. Calcium and sodium soaps once are used in steel wire rod (wire) drawing and aluminum stearate soaps are generally used in drawing operations with thick cross-sections such as bolts and nuts (Wright et al., 2011; McNulty, 2006; Eickemeyer et al., 1996; Brard, 1991). The solid lubricants used in the wire drawing process are miscible with the metal parts stripped from the wire surface during the reduction process and become wastes that must be disposed of at the end of the process. The generated waste cannot be used once for the same process with the waste state. The waste soaps subject to recycling have been classified as hazardous waste by the competent authorities of developed countries. These hazardous wastes have limited storage times and have to be disposed of (Sarma and Vinu, 2022).

Characteristic analysis such as FTIR, TGA, XRF, SEM and light microscopy were applied in soap conversion. In addition, the wires drawn with converted soap were evaluated in terms of mechanical properties. Tensile strength and torsional properties were examined. In addition to the mechanical strength after recovery, the deformations on the wire surface, the growth in the rolling diameters and the changes in the rolling temperatures were taken into consideration. With this study, it is aimed to transform the waste soap, which is classified as hazardous waste (Tripp, 1998), to be used in wire drawing without harming the environment and living things, and to contribute both financially and environmentally. The methods used during the recovery process are physical and do not involve a chemical process. This paper proposes tools for the physical separation. Therofere, due to the physical separation there is no new side waste during the recycle process. And with its low energy consumption, it is suitable for automation ensuring that this process fulfills many criteria of green recycling processes.

EXPERIMENTAL AND RESULTS

Design of New Experimental Process

The size distribution of soap and metal parts in the waste varies according to the run times of wire drawing and reduction rates. In the laboratory-scale studies, waste samples were sieved by using sieve systems with pore sizes ranging from 2 to 300 mesh. In the selection of the sieves used in the sieving process of the wastes, the sieve analysis made on the original soaps was also taken into consideration. Sieve analysis test results are shared in Table 1.

Table 1. Sieve Analysis Results for Original Lubricant Soap

Characteristics	Unit	Value	Low Limit	High Limit
PARTICULE SIZE - D10% IN MM	mm	0.33	0.24	0.57
PARTICULE SIZE - D10% IN MM	mm	0.33	0.24	0.57
PARTICULE SIZE - D50% IN MM	mm	0.98	0.80	1.52
PARTICULE SIZE - D90% IN MM	mm	2.29	2.16	2.67
PARTICULE SIZE - XM IN MM	mm	1.16	1.00	1.56

Waste and soap sifted in sieves with different pore diameters were classified according to their particle size. In this way, the size-separated waste was made ready for the magnetic separation, which is the next step. In the laboratory-scale separations, a neodymium magnet was placed approximately 10 cm sized the continuously stirred waste's above, thereby removing metal impurities from the waste. With the removal of metal impurities, ready-to-use recycled soap is left behind (Fig. 2).

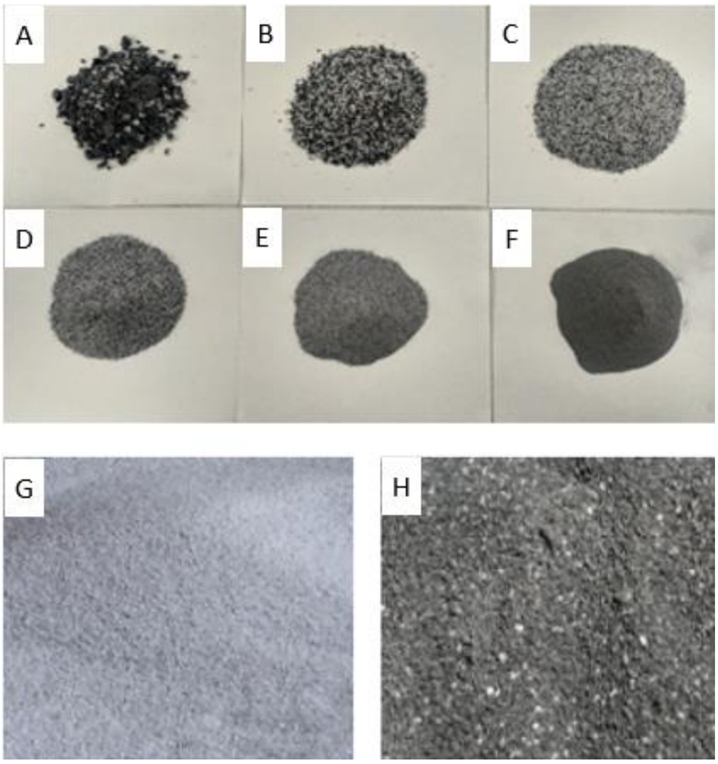

Fig. 2. Waste Samples of Different Sizes (A), (B), (C), (D), (E), (F), Subjected to Sieving Processes, Soap (G) and Metals (H) Obtained After Magnetic Separation

After optimizing the laboratory-scale separation process, the process of establishing an industrial-scale soap recycling system was carried out. For this, an automated system was developed by imitating the system developed at the laboratory scale. In this system, the wastes are transported to sieves with a size of within the range 6-100 mesh, which are constantly vibrating, by a conveyor belt system and are separated according to their sizes on these sieves. Since the wastes have a wide size distribution, a more efficient magnetic separation process was achieved by using a multi-sieve system.

After the sieving process, the wastes are passed through belts and metal impurities are separated from the wastes by using the magnets with a power of 5000-15000 Gauss on each layer of these belts. A representative recycling system with single band is shown in Fig. 3. Soaps obtained in different sizes are mixed and reused in the appropriate wire drawing processes. All stages are shared in Fig. 4.

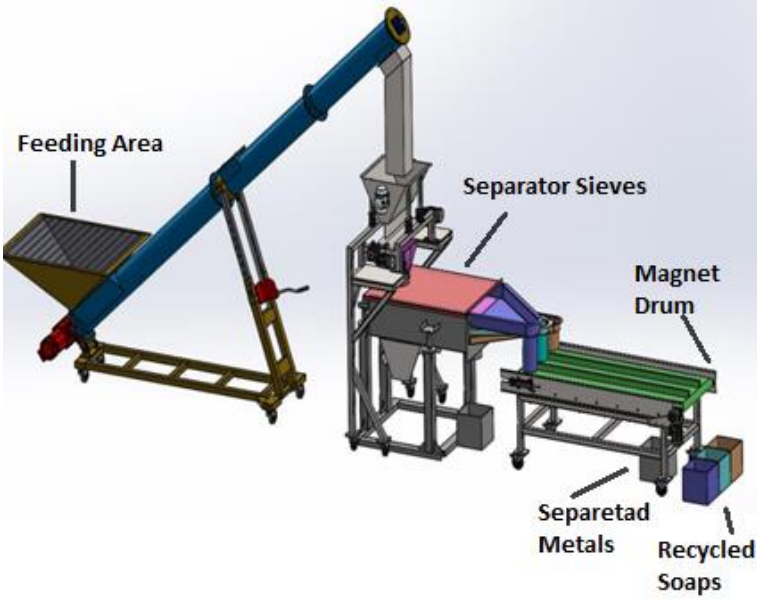

Fig. 3. The System Design for Recovery

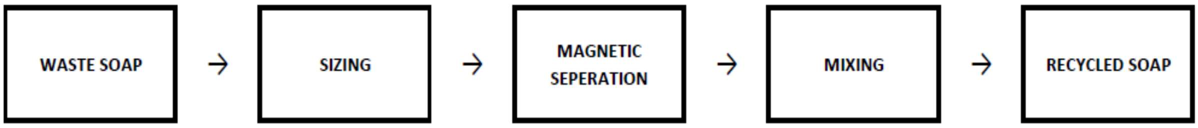

Fig. 4. All Stages for Recovery

The Characterization of Recycled Soap Powders

Instrumentation

Zeiss Evo LS10 model SEM analyzer and Leica Brand DM 750 M model light microscope were used in the analysis of the wire surfaces. Panalytical Brand Axios Advanced model XRF spectrometer was used in clarification of the chemical composition of waste and recycled soaps. Perkin Elmer 400 FT-IR / FT-FIR spectrometer device was used in clarification of the chemical composition of pure, waste and recycled soaps. TGA/DTA analyses were carried out for characterization of pure, waste and recycled soaps (Perkin Elmer Diamond model TG/DTA). The tensile strength of the wires was measured with the Zwick/Roell Z050 tensile device.

Analysis and Evaluations

Hot water extraction was used to determine the soap quantity in the waste sample. In this method, the sodium-based soap dissolved in hot water (~ 90 0C), while the remaining wastes did not dissolve in water. When the aqueous part was filtered by the filtration method, the sodium-based soap dissolved in hot water and the waste part were separated from each other. Quantification was carried out by weighing the remaining soap after the water was removed by evaporation. The results obtained show that there is 67% of usable soap in the waste obtained after the wire drawing reduction process.

This novel physical recycling process has been applied to recover 88% of soap in the waste, and the recovered soap has been successfully used in wire drawing without causing any deformation of the wire. In the literature, a unique scientific research paper is available that proposes a technique in terms of soap particle recovery with a rate of 85.45%

(Kim et al., 2014). When you explore some published patents on the same field, you see lubricating powder recovery device solution offers (Zhendong, 2011; Gyucheol and Giate 2010). But unfortunately, there is no information for the recovery rates. Only 2 patents are found. One has the title of "Dry Drawing Lubricant Recycling Machine for Steel Wire", having the feature to remove up to 98% of iron pollutants at a cost of 50 liters per hour (Mun and Kyung-ho, 2011). And the other one with the title of "Wire drawing dry lubricant recycling machine", shows a result of removal rate of the iron powder can be 80% or more just for a sample they investigated (Toru, 2005).

XRF analysis was carried out for clarification of chemical contents of pristine, recovered and waste soaps. Sodium-based soap was recovered in this process, therefore the sodium (Na) ratio was taken as a basis in the pristine, recovered and waste soaps. It was found that the sodium ratio in the recovered soap is parallel to the sodium ratio found in the original soap. Like sodium (Na), other elements including potassium (K), phosphorus (P) and silicon (Si) ratios have almost the same percentage values compared to the original soap. A decrease in the rate of sodium and an increase in the rate of other specified elements were observed in the wastes consisting of a mixture of soap and metal, which are described as waste soap, due to metal impurities (Fig. 5). The results obtained showed that the waste soap could be recovered with an efficiency of over 95%.

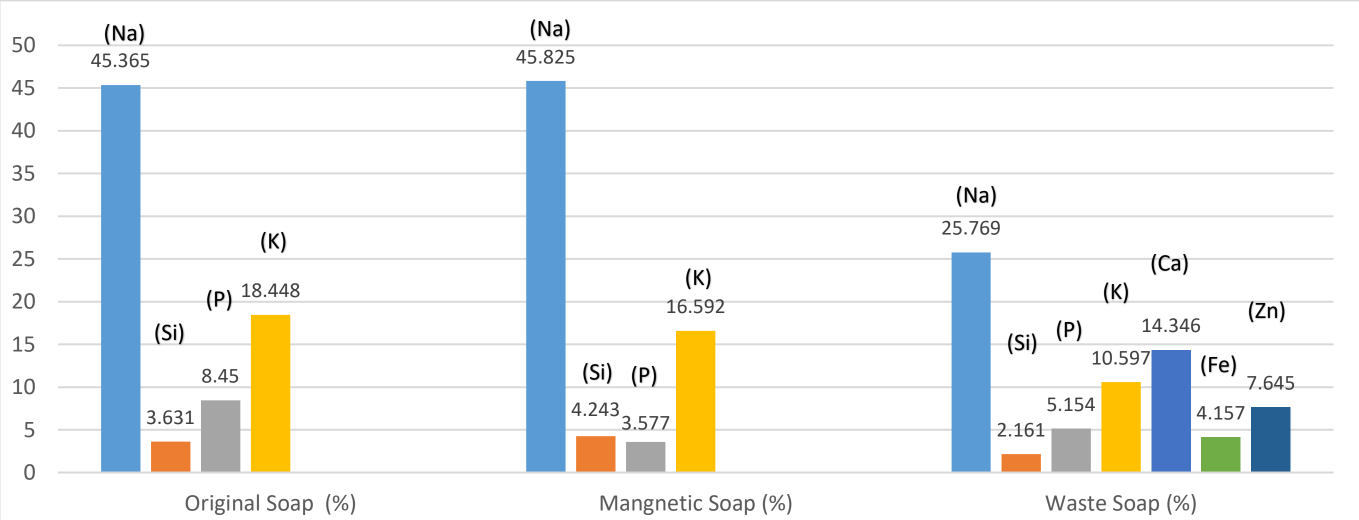

Fig. 5. XRF Analysis of Unused (Original), Recycled and Waste Soaps

FT-IR analysis were also conducted to determine if impurities remain in recycled soap and to observe chemical differences between original unused soap and recovered soap samples. It is predicted that the absorption peaks occurring above 3600 cm^{-1} in the samples are caused by O-H vibration peaks. Similarly, C = C peaks occurring in the range of 1400-1600 cm^{-1}, C-O absorption peaks occurring around 1100 cm-1 (Fig. 6). When the FT-IR spectrum is examined in the two samples, it is seen that there is no significant difference between the spectra and even the spectra are very close to each other. FT-IR results prove that waste soap is successfully recycled.

The thermal behaviours of the original unused soap and recovered soap was also investigated to illuminate if impurities remain in recycled soap and to observe chemical differences between original unused soap and recovered soap samples. The results obtained from TGA analysis show that both samples do not deteriorate up to 350 °C and their chemical structures begin to change above 350 °C (Fig. 7). When both TGA spectra are examined, it is seen that both soap samples give very similar and compatible thermal degradation graphs.

By using the unused original soap and the reclaimed soaps, the wire drawing reduction process was carried out for the 5 km long wire. After the wire drawing reduction process, the surface structures of the wire samples were examined with using scanning electron microscope (Fig. 8) and the light microscope (Fig. 9) techniques. When the images obtained from both methods were examined, it was clearly seen that there was no deformation such as scratches or breakage on the wire surfaces and it was also observed that there was no significant difference in the morphology of the wire surfaces.

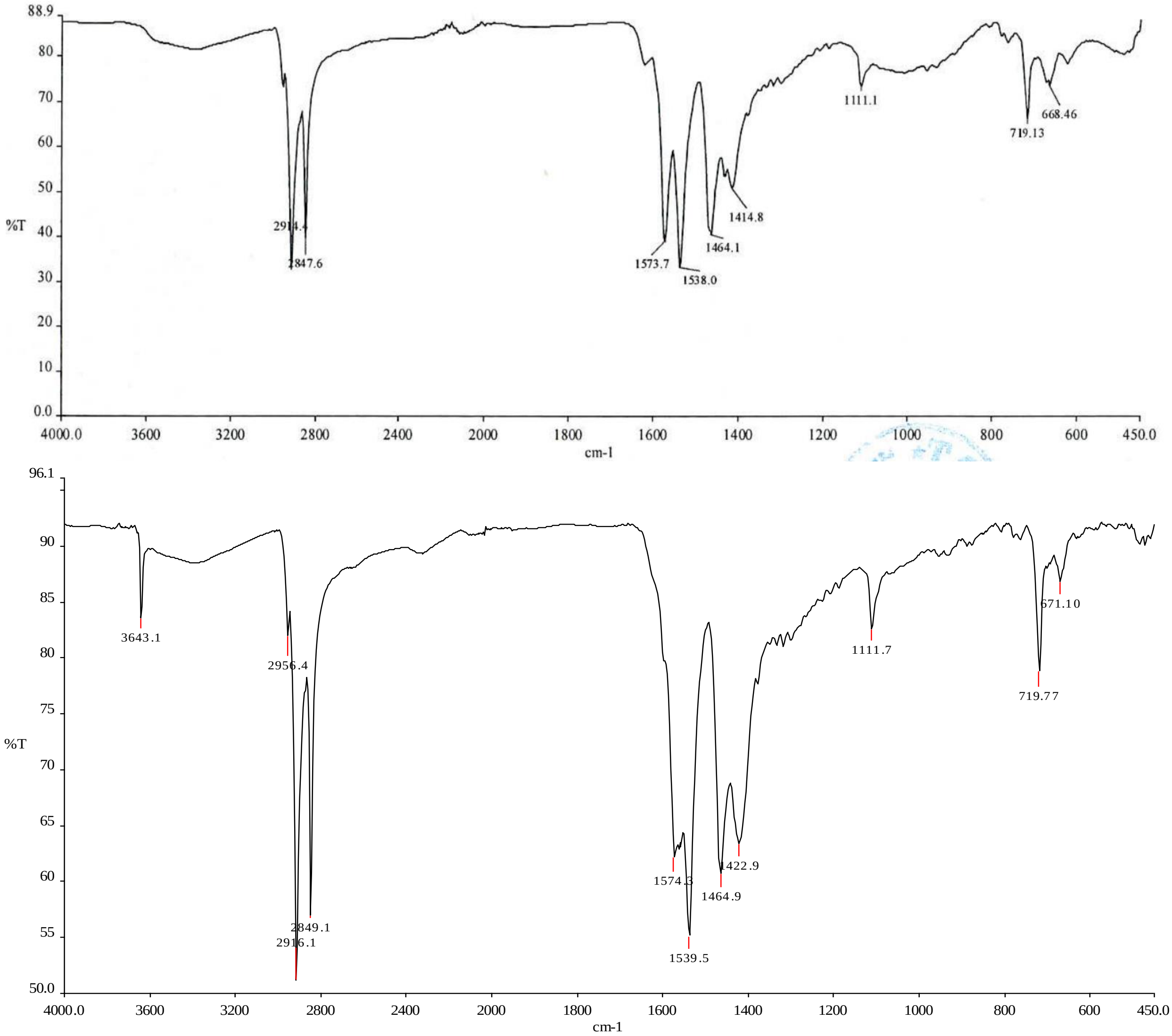

Fig. 6. FT-IR Spectrums of Recovered Soap (A) and Original Unused Soap (B)

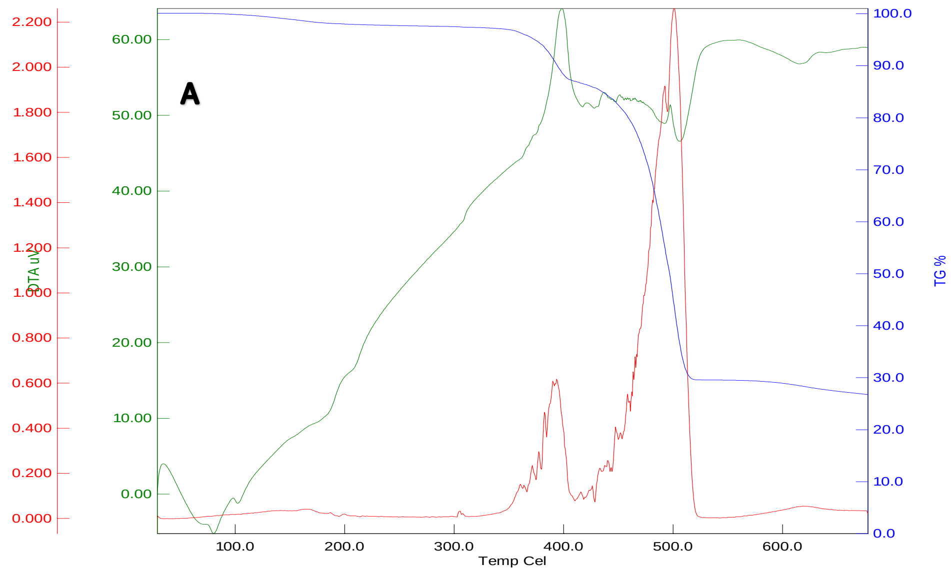

Fig. 7. TGA/DTA Analyses of Original Unused Soap (A) and Recovered Soap (B)

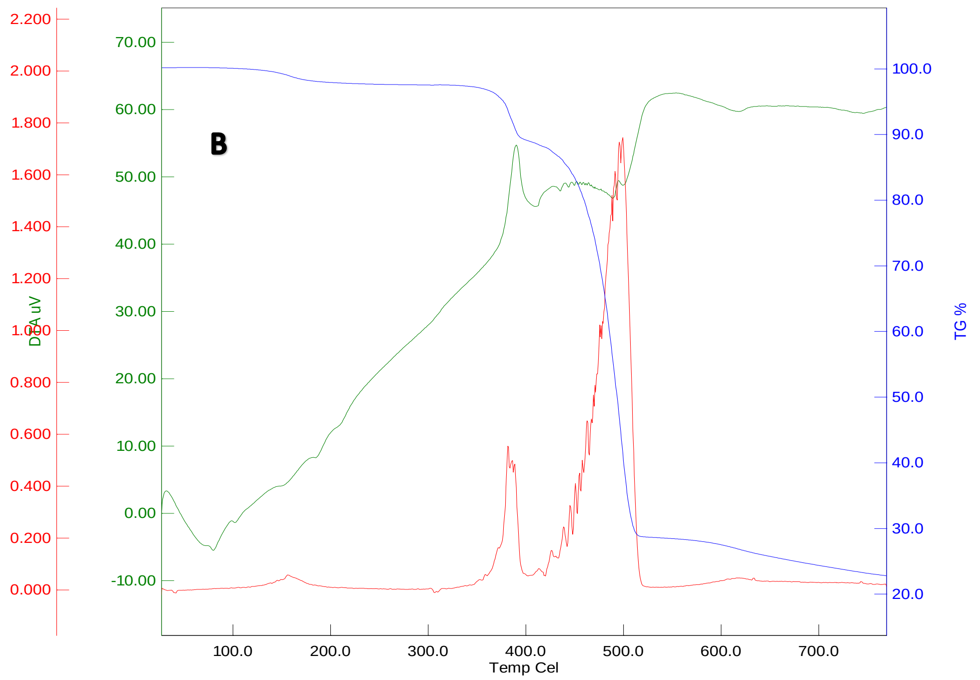

Fig. 7. TGA/DTA Analyses of Original Unused Soap (A) and Recovered Soap (B)

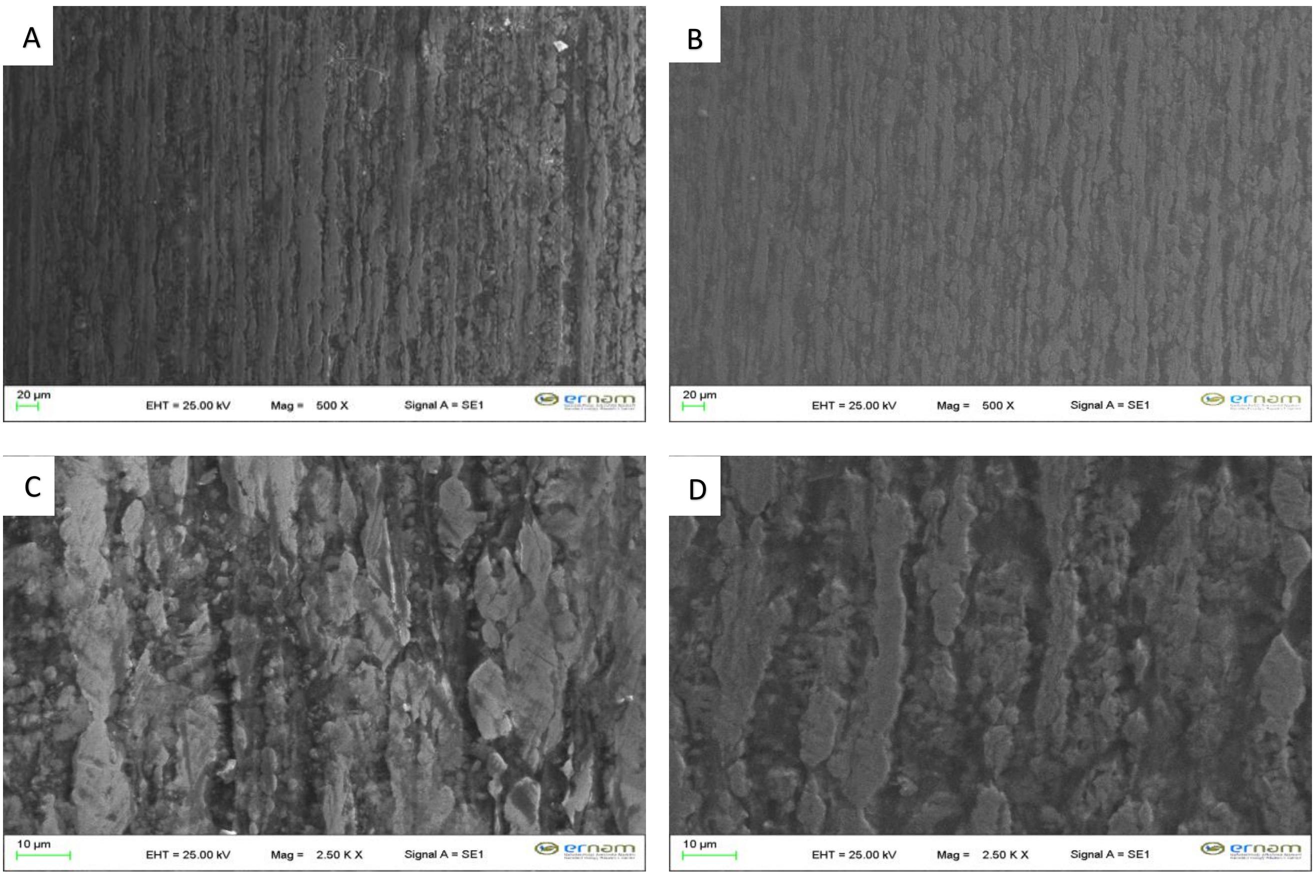

Fig. 8. SEM Images of Drawn Wire by Unused Soap at 500 X Magnification (A), SEM Images of Drawn Wire by Used Soap at 500 X Magnification (B), SEM Images of Drawn Wire by Unused Soap at 2.50 KX Magnification (C), SEM Images of Drawn Wire by Used Soap at 2.50 KX Magnification (D)

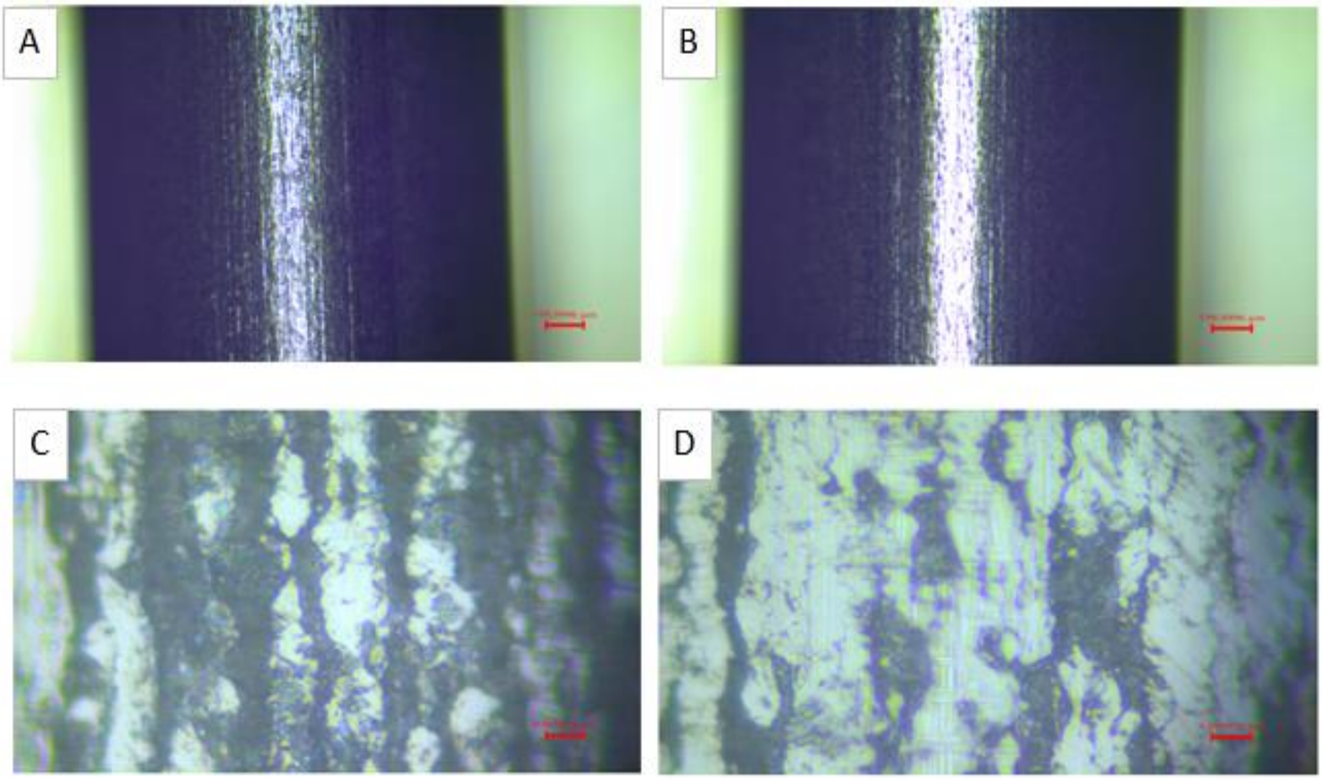

Fig. 9. Light Microscope Images of Drawn Wire by Unused Soap at 5 X Magnification (A), Light Microscope Images of Drawn Wire by Used Soap at 5 X Magnification (B), Light Microscope Images of Drawn Wire by Unused Soap at 100 X Magnification (C), Light Microscope Images of Drawn Wire by Used Soap at 100 X Magnification (D)

Mechanical properties of wire rods that were the original soaps and the recovered soaps were compared by doing in the wire drawing reduction process for the 5 km long wire. The tensile strength and twisting amount of the wires were measured. The tests in the graphics shown in Figure 10 were made according to the EN 10270-1: 2011 standard (EN 10270-1, 2011). According to the samples 1, 2 and 3 shown in the graphs, the bars on the left represent the wires taken from the original soap draw, and the bars on the right represent the test data applied to the wires drawn with soap recovered from the waste. According to the EN 10270-1: 2011 standard; the maximum tensile strength is 1710 MPa, the minimum tensile strength is 1490 MPa (Fig. 10) and the minimum number of twists is 22 (Fig. 11). During the reduction process of the wires, there should not be any deformation on the die surface. Diameter growth in dies should occur at the desired level and time. After wire drawing using the original soap and the recovered soap, there was no difference in the changes in the die diameter.

XRF, FT-IR TGA and DTA analysis were performed to elucidate the chemical structures of the recycled soap and the unused soap, and the results showed that the chemical content of the original soap and the recycled soap were very close to each other and exhibited similar characteristics. When the scanning electron microscope, light microscope and mechanical test analysis of the wires produced in the wire drawing reduction processes with the recycled soap and the original unused soap were examined, it was shown that the wire properties obtained after both production were the same. In other words, all studies showed that the recovered soap exhibited the same lubricating properties as the original soap.

The original soaps have a certain size distribution within themselves, the smaller the grain size, the less the separation rate. The inability to the recover soaps with very small micron size can cause problems in small diameter wire drawing processes. The expressed soap particles can be increased by reducing the mesh intervals of the sieves used in the sieving system and increasing the number of sieves.

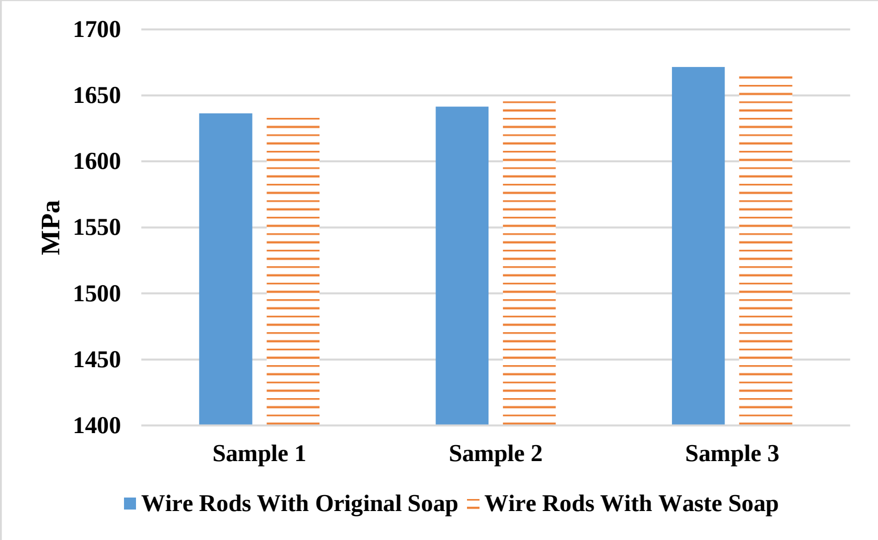

Fig. 10. Wires' s Tensile Strength and Torsion Number

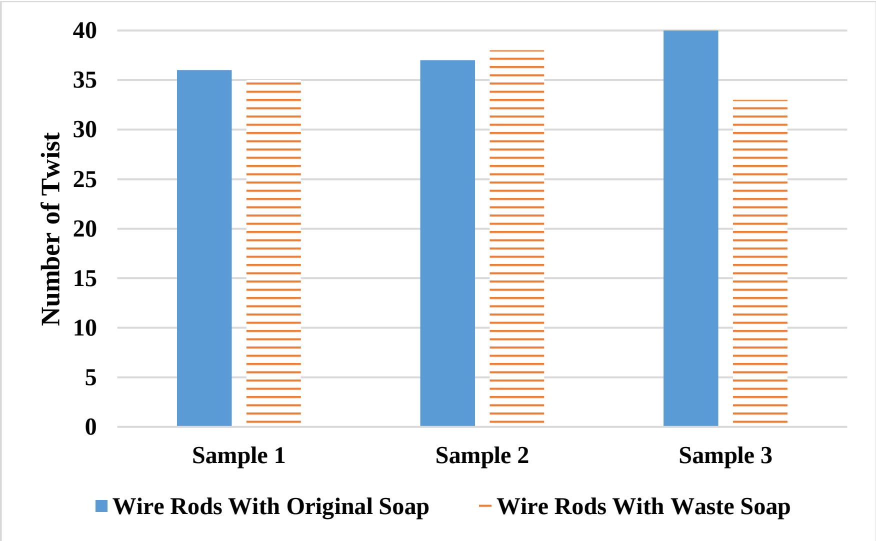

Fig. 11. Wires' s Torsion Number

CONCLUSION

It has been determined that 67% of the waste left after the wire drawing process is lubricating powder soap, while the remaining 33% is composed of other impurities, mostly metal powders. In order to the recycle solid die soaps used as lubricants in industrial wire drawing processes, a simple and cheap method and prototype system based on physical separations including sieving and magnetic separation stages has been developed. It is clear that our rate is better when you compare the values. The characterization techniques performed have proven that there was no change in the chemical properties of the soap in the waste and both physical and chemical properties of the recycled soap were largely similar to the original soap. In this recycling process based on physical separation, there is no chemical process based on chemical consumption, it does not leave secondary waste to the environment, it has low energy consumption and is suitable for automation, which ensures that this process meets many criteria of green recycling processes.

CONFLICT OF INTEREST

The authors do not have financial and personal relationships with other people or organizations that could inappropriately influence their work.

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DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Orhan EREN: He wrote the article. He was involved in laboratory studies, field trials, prototype studies and tests. He provided making of characterization analysis and interpretation. He provided coordination.
Eyyup GERÇEKCİOĞLU: Within the scope of the project, he supervised the master's thesis, contributed to the interpretation of the tests and analysis and to the writing of the article.
Esra BENLİCE: Contributed to article writing. He was interested in laboratory studies, prototype studies and tests.
Erkan YILMAZ: He participated in laboratory studies, contributed to the interpretation of tests and analysis and to writing articles.
Ali DURAN: He participated in laboratory studies, contributed to the interpretation of tests and analysis and to writing articles.

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