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EROSION WEAR ANALYSIS of SS 430 MATERIALS and OPTIMIZATION USING THE TAGUCHI APPROACH

[1]Tushar Sharma, [2]Gurmeet Singh, [3]Harjit Singh Gill

[1]Research Scholar Department of Mechanical Engineering, Chandigarh University, Mohali, India.

[2,3]Associate Professor, Department of Mechanical Engineering, Chandigarh University, Mohali, India

Abstract: Sludge erosion in India's hydropower plants is a serious problem, especially for projects located in mountainous terrain. To solve this problem, a study was carried out using a mud pan tester to optimize the erosion wear of the material. In this study, optimization of erosion wear analysis using the Taguchi approach has been presented. SS 430 is used as a test specimen, and the erosion effect is investigated by changing the rotation speed, particle concentration, and duration. Different particle sizes of different particle concentrations 45%, 60%, 75%, 95% were used in the experiment. The experiments were performed at different duration, the 60s, 90s, 145s, and 210s, respectively. The efficiency of the uncoated and the coated material has been examined. For coating Cr and Al_2O_3 material in the ratio of 60:40 has been sprayed using a well-known High-Speed Oxygen-Fuel spraying process with a thickness of 160 to 350 μm, and the result was tested using the Taguchi approach. The experiments showed improved erosion wear of material SS 430 while protecting material with a $CrAl_2O_3$ coating. The order of the parameters influencing the material's erosion wear was like time >rpm >concentration >particle size.

Keywords: Erosion wear, Slurry pot tester, High-Velocity Oxygen-Fuel, Taguchi approach.

1. Introduction

Currently, slurry transport is a significant area of research. Its application is found in many fields such as coal, iron ore, copper, drilling, paper and pulp, sewage pumping, and agricultural waste. It is a mixture of different types of solids that are of varying shapes or sizes and are usually found in size of a millimeter or micrometers. These particles were transported using liquid as a carrier [1]. As technology advances, production capacity in mines and other solid industrial wastes increases daily. The disposal of highly concentrated slurry material is associated with major economic concerns by the mining industry in many countries [2]. The problem of transporting these minerals and deposits is huge. Conventional transport modes are less efficient, require large capital investments, and have environmental disadvantages. Slurry material is transported around the world through these pipelines. The main disadvantage of these pipelines is the wear resistance to the transportation of slurry material [3]. Abrasion ability mainly depends on the material's particle size, shape, hardness and particle velocity. Analyzing the amount of wear is the most essential need today. This will help predict the wear of the pipes and thus the service life of the pipeline. It will also help you plan maintenance to maintain the quality of the material. Materials behave differently depending on the type of slurry and different types of repairs [4].

In addition to corrosion, large part of the equipment installed in the transportation of slurries miiight be damaged due to the erosion mechanism. For the first time, the mechanism of slurry erosion was studied by researchers Finnie [5] and Bitter [6] in the 1960s. Since then, several researchers have made efforts to discover the rate and cause of erosion and find a solution to solve this problem and thus increase material life.

In this research, different factors that cause erosion were taken into consideration. The optimizations have been done using the Taguchi approach. SS-430 material has been considered and results were examined without and with coated material. Fly ash has been considered erodent material and experiment has been conducted by examining the time, concentration, and rotation speed. Pot tester has been used to experiment at a different time and different concentration of slurry.

2. Related work

Forder et al. (1998) have presented an erosion model based on the computation of fluid dynamic that predicts erosion rate within chokes. Using the particle movement information from the particle trajectories, the erosion rate variation has been analysed in terms of particle impact features, types of material, and shape & size of particle [7].

Praveen et al. (2016) have studied and tested effect on erosion wear rate of SS 304 material. The specimen was coated with NiCrSiB, and WC–Co of 65 % and 53 % respectively using the process of HVOF spraying. Taguchi approach has been considered as an optimization a method to optimize the sprayed factors such as rate of oxygen flow, flue flow, rate of feeding powder and the stabling distance of the gun from the material. The optimized parameters using Taguchi approach in increasing order are (i) distance, (ii) powder feed rate, (iii) fuel flow rate, (iv) oxygen flow rate. At last, the erosion ware rate of the optimized coating has been performed at three angles such as 30°, 60° and 90° [8].

Singh et al (2018) have worked on to optimize the erosion wear of the slurry impeller substance, SS 410 has been utilized as the most commonly used pump impeller material with Fly Ash as the erodent material. The sprayed material parameters have been optimized using Taguchi approach. The experiment reveals that desired enhancement in the resistance against erosion has been analysed using WC-10Co-4Cr as a coated material. The test has been performed with coated as well as uncoated material and the influenced parameters have been examined. It has been concluded that the coated SS material performed better resistance against erosion in contrast to uncoated SS material [9].

Rawat et al. (2017) introduced an improved pot test in which the test is conducted at a higher concentration. A different concentration of fly ash was used, its speed varies between 50-70 percent in the range of 1-4 m/s. Erosion wear was analyzed at higher and lower concentration. Thus, the results reveal that the rate of erosion depends more on the concentration of the material than on the velocity. The maximum erosion rate was observed at 45° at 65% solids concentration [10].

Singh et al. (2017) have studied the effect of solid liquid mixture on the SS 304 in terms of erosion wear. Fly ash in combination with sand has been used as an erodent material mixed in concentration of 20 – 60 %. The test has been examined at various speed ranges from 600 rpm to 1500 rpm in a step of 300 rpm. The target material has been protected against erosion by spraying WC–10Co–4Cr and Ni–20Cr_2O_3 as erodent material using HVOF gun. The test results reveal that the erosion rate depends upon the speed of rotation, duration and type of solid particles. When Ni-20Cr_2O_3 has been covered with WC–10Co–4Cr as coated material the erosion wear rate has also been increased [11].

Zhao et al. (2015) have studied the impact on erosion wear of AISI- 316 material under the high-speed imping mentation by a mixture of sand liquid. Silica and sea sand have been used to determine the influence on operating time as well as on chloride ions and observed that the weight of the specimen has decreases with the passage of time. The weight loss has been reduced by the smallest size particle. Also, with the increase in the impact angle, the weight loss reduces. The erosion appear on the target material in the occurrence of sea sand is higher compared to the silica sand. At an impact angle of 60 degree, the material shows better corrosion resistance [12].

Xie et al. (2015) have discussed the wear mode against erosion for slurry transport material. Slurry abrasion response (SAR) for chosen target materials have been performed and analysed that the low alloy pipe steel has highest response compared to AR 400, AR 600 steel. The erosion wear has been affected by the random movement of solid particles at distinct impingement angles [13].

Wang et al. (2016) have tested the erosion resistance of ANSI 1020 as carbon steel and ANSI 4135 as alloy steel material by using Ultrasonic Vibration Apparatus. The test has been conducted under distilled water and pure water respectively. The microstructure analysis shows that ANSI 1020 have higher mass loss compared to ANSI 4135. Also, the rate of erosion has been analysed by ANSI 4135 material is much higher while testing under tap water instead of distilled water. This is because of the presence of iron oxide in tap water [14].

Singh (2021) have studied the slurry erosion failure of SS 316 L steel. The material was coated with HVOF. The test has been conducted using a pot tester for different time instant. To study erosion wear phenomenon sand particles were used as an erodent. The results show that the erosion wear rate was significantly affected by the slurry concentration percentage, time duration and rotation speed [15].

Haque et al. (2022) have presented the experimental and testing of SS 404 material erosion wear property. The erosion wear was tested on the SS- 404 material, which coated with 80 % of WC and 20 % of Ti O_2. The testing has been performed in a slurry pot tester that contains slurry mixture, mixed with fly ash. The test was performed at different particle sizes and different rotation speed [16].

3. Material and Methods

For experiment, SS 430 is used as a test specimen that is available in cylindrical shape having diameter 30mm. The test specimen is then cut into a piece having dimension 50× 25 mm. 8mm hole has been drilled at the center of the specimen, and the prepared specimen is as depicted in Figure 1.

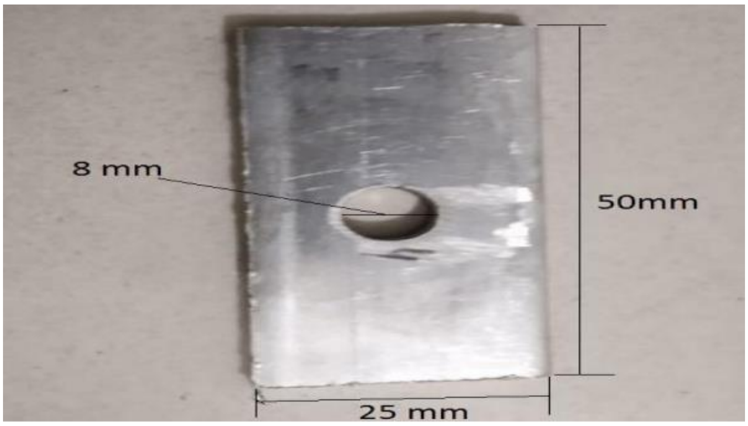

Figure 1: Prepared Specimen of SS 430

3.1 Erodent material

Fly ash has been adopted as erodent material. This was collected from the thermal power plant situated in Punjab, India. The surface morphology of the material has been conducted using Scanning Electron microscopy and the material was found to be ceno-spherical. The sample of fly ash is shown in Figure 2.

Figure 2: Fly Ash

3.2 SS 430

AISI 430 is the most sought after corrosion resistant ferritic steel for general applications. It has good properties, characteristics, ease of processing, high resistance to inter crystalline corrosion and oxidation at high temperatures. The low carbon content of AISI 430 makes it possible not to additionally stabilize the steel with titanium. Due to the low content of molybdenum and nickel, the price of steel 430 is cheaper than steel 300 of the series. The chemical composition of steel is written in Table 1.

Table 1: Chemical Composition

Element	c	mn	si	p	s	cr	Fe
Percentage (%)	0-0.08	0-1	0-1	0-0.04	0-0.02	16-18	balance

4. Methodology

A slurry pot tester was used for the experimental work. Uncoated target materials, SS-430 was considered as testing material to analyze and determine the erosion wear. The slurry pan tester is a suitable testing device for steel and is used for rapid response to erosion. Slurry pot tester comprises of a cylindrical aluminum tank in which the mixing of slurry and liquid has been performed.

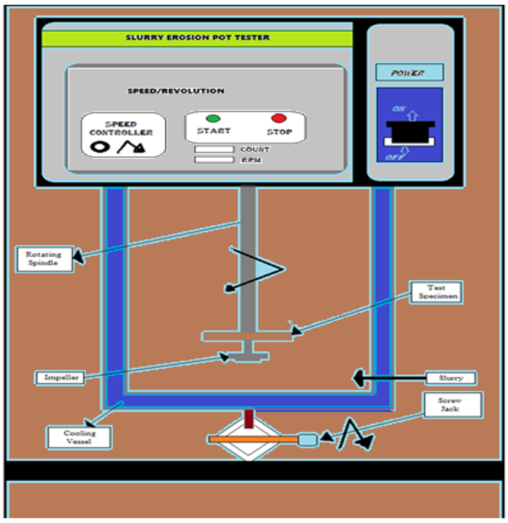

Figure 3: Slurry Pot Tester

A rotating shaft is used to clamp the material. There is an electric motor to rotate the shaft and it is on the top side of the tester. The spindle can run at a maximum of 1500 rpm. During practice, the inner cylindrical pot can be adjusted as needed. Also, rotating shaft's speed can be adjusted with the speed knob available on the boiler tester. The testing was carried out by fixing the sample to the spindle and lifting the cylindrical pot containing the mixture by means of a jack and fixing it as necessary. The testing was carried out at a maximum speed of 1300 rpm at different times of 60s, 90s, 145s and 210 s. The concentration of the eroding mixture was 45, 60, 75, 95 % by weight of solid and liquid.

5. Result and Discussion

The foremost test conducted on the specimen is the optimization of various parameters using the Taguchi approach. Performance was done based on re-evaluation rate, solids concentration, time duration, and average particle size.

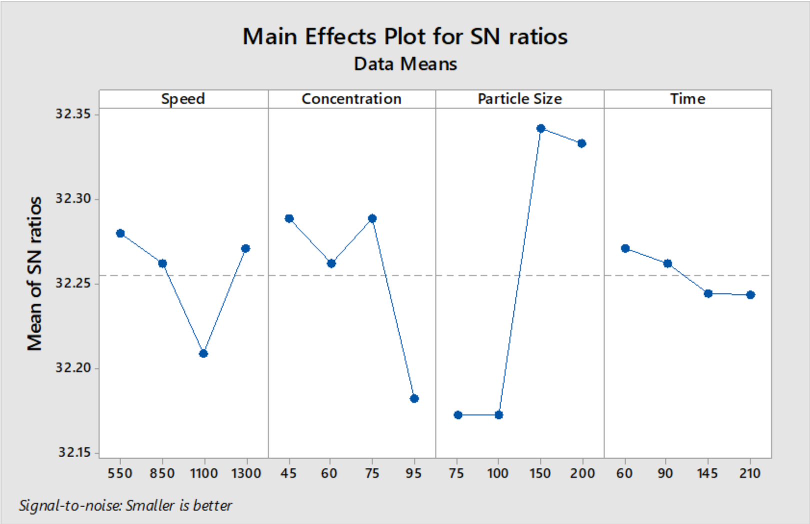

Figure 4: The mean effects plot for SNR of Uncoated SS 430

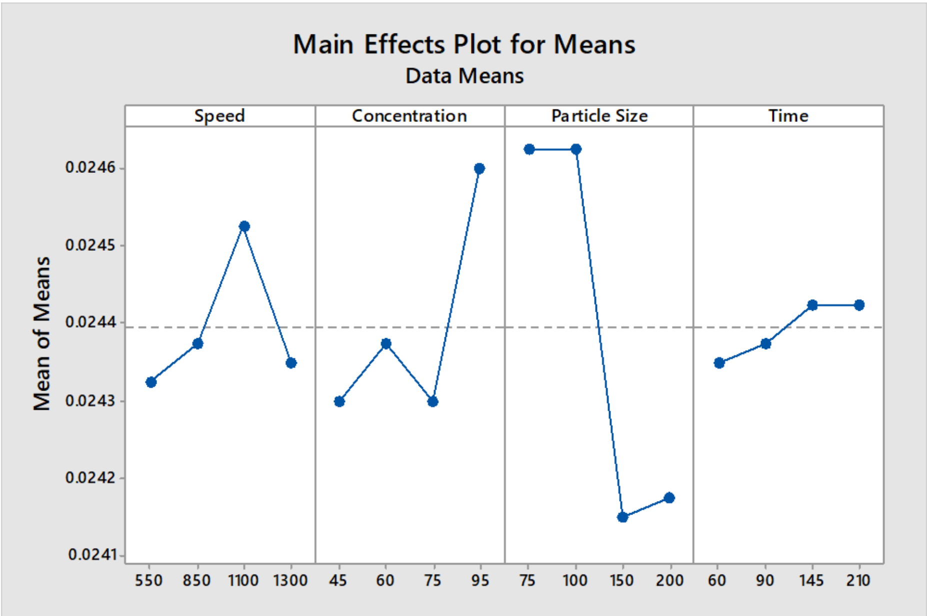

Figure 5: The mean effects plot for mean data of Uncoated SS430

Figure 4 represents the graph of means of S/N ratio for four different examined parameters. These are speed, concentration, particle size, and Time. In the similar way, plot for all the mentioned parameters using Taguchi approach has been analyzed for means of means. The results are plotted in Figure 5.

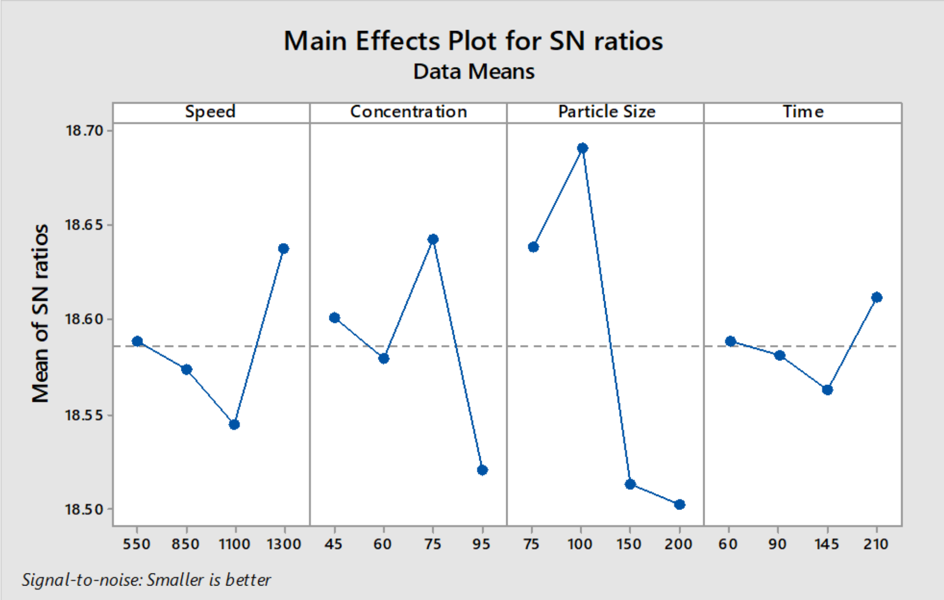

Figure 6: The mean effects plot for SNR of Uncoated SS430

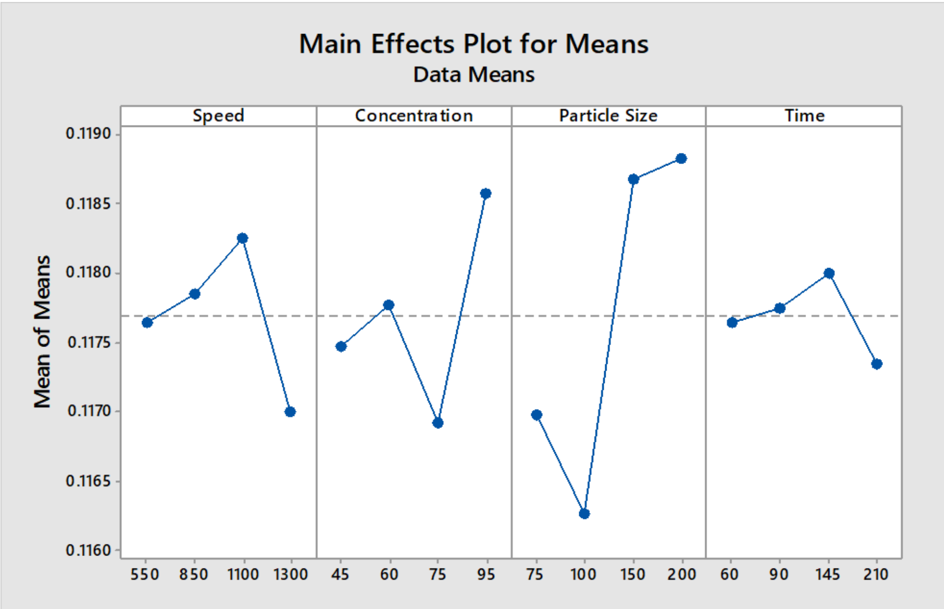

Figure 7: The mean effects plot for SNR of Coated SS430

The SEM and EDX images for the considered fly ash are illustrated in Figure 8. The fly ash particles of size smaller than 10 mm and more than this are considered as coarse particles.

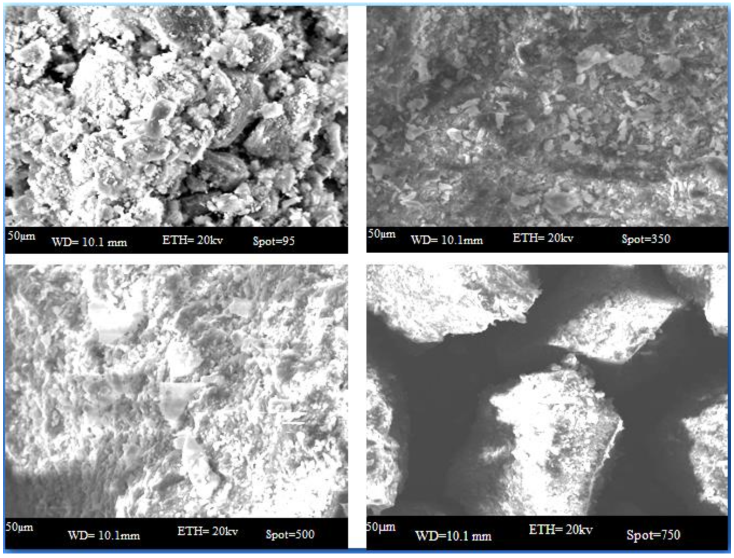

Figure 8: SEM of fly ash sample having particle size range of (a)104–150mm (b) 150–216 mm (c)216–300mm, and (d)300-340mm

The morphological structure of fly ash was depicted in Figure 8. The spherical shapes visualized in the images are the fly ash particles. This morphological operation can be controlled by controlling the rate of cooling and temperature. From the obtained image, the particle size varied between 104 mm and 340 mm. Particles of size 104 mm and 150 mm are considered as solid spheres.

Figure 8 (b) shows cenospheres with uneven spacing along with irregularly shaped carbon particles. Minerals representing surface dissolution are depicted in Figure 8 (c). Irregularly shaped amorphous particles are depicted in Figure 8 (d).

When conducting SEM analysis of the tested sample at the lowest impact parameters such as 700 rpm speed, 50% concentration, 70 minutes time, it was found that craters and wear marks such as small erosion were minimal in most of the parts as shown in Figure 9.

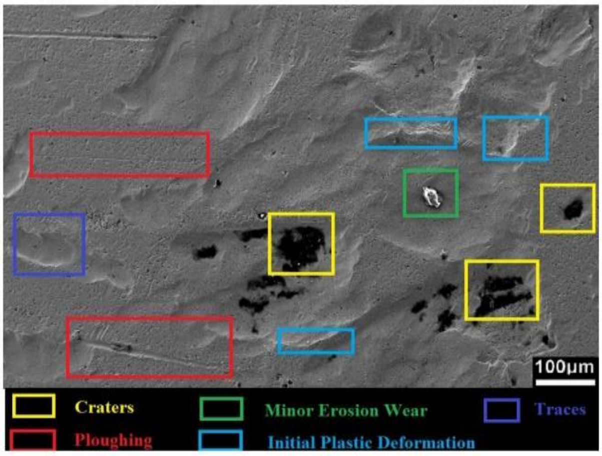

Figure 9 SEM Image at the Lowest Impact Parameters

Figure 10 shows a highly eroded surface for the most part, while craters appear to be minimal after SEM analysis at the lowest impact settings of 1300 rpm speed, 72 % concentration, and 140 minutes time.

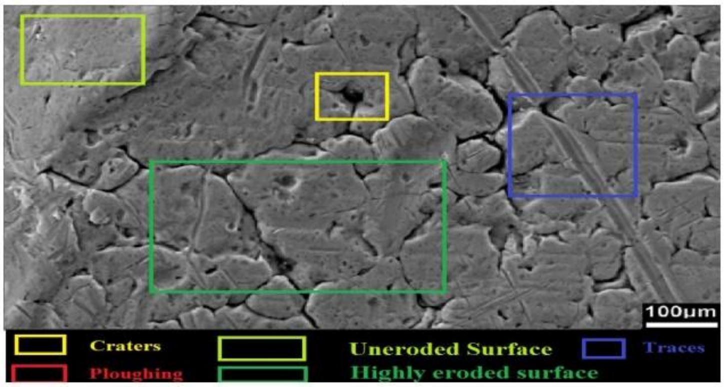

Figure 10 SEM Image at the Highest Impact Parameters

6. Conclusion and Future Scope

From the above research, it was determined that erosion occurs only when the solid-liquid mixture is transported through the pipelines, while wear is a material loss caused by mechanical interaction between components. This is one of the main causes of failure of mechanical components. This study was used to analyze the erosion wear rate in SS 430 material and it was observed that several factors are responsible for the erosion wear. These factors have been considered and discussed in this study. Observation of these factors shows that if these factors are controlled and minimized, the life of machinery and material can be extended. Some of the observed points are summarized below;

i. Cr Alo_3 has been used as covering material for SS 430 that offers better results in contrast to uncovered SS 430.
ii. Experimental time is directly proportional to the erosion wear.
iii. The XRD results reveal that the specimen after inter-contacting was oxidized.
iv. The SEM also reveals that the metal foams have more closed pores compared to open pores.

In future the work can be extended in the following ways:

- Erosion wear testing can be performed using another coating approach such as plasma coating.
- The results can be analyzed in different working conditions.
- The test analysis can be performed by mixing different concentrations of solution and using a different instrument for the pot tester.
- Other material using a different composition may be used as a test sample.

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