



# INVESTIGATION ON THE SLURRY EROSION BEHAVIOUR OF SUPER 304HCu STAINLESS STEEL UNDER NORMAL IMPACT CONDITIONS

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## ABSTRACT

Slurry erosion is an important wear issue in pipelines, pumps, and other industrial equipment that operate in environments where solid particles are transported along with the liquid. In this study, the slurry erosion behaviour of Super 304HCu alloy is examined under different simulated conditions, including slurry velocity, slurry concentration, and time of exposure. The experiments for these investigations are carried out in a slurry erosion test rig at various rotational speeds of 6 m/s, 9 m/s, and 12 m/s, with varying slurry concentrations of 10%, 20%, and 30%. The weight loss of the test specimens was recorded at regular intervals to determine the erosion rate. The experimental results indicate that the weight loss of the material steadily increases with increase in time of exposure, slurry velocity, and slurry concentration. At higher slurry velocities the increase in kinetic energy of the abrasive particles, result in stronger impacts on the material surface and consequently increase material removal. Similarly, the increase in slurry concentration increases the probability of the number of particles interacting with the surface, and accelerates the erosion process. SEM micrographs of the worn surfaces of the specimens revealed typical wear characteristics of erosion of a ductile material.



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## I. INTRODUCTION

Slurry erosion is a complex wear phenomenon caused by the repeated impact of the solid particles suspended in liquids on material surfaces. This type of wear is commonly encountered in heavy systems such as slurry pipelines, pumps, hydro turbines, mining equipment's, and power plant components [1]. The erosion process involves several material removal mechanisms, such as micro-cutting, plastic deformation, and surface fatigue, which in turn depend on factors such as slurry velocity, slurry concentration, particle size, and angle of impingement [2-10]. In recent years, significant research has been carried out on understanding the tribological wear mechanisms responsible for the slurry erosion and development of materials with improved resistance to such damage. Li et al. investigated the mechanisms of slurry erosion and reported that erosion is strongly influenced by particle velocity and angle of impact. It is also demonstrated that ductile materials tend to experience maximum erosion at oblique angles of impact, typically between 30° and 60°, where micro mechanism such as both cutting and deformation contribute to material loss [11], [12]. Several studies have also focused on the erosion resistance of stainless steels in slurry environments. Examined the slurry erosion characteristics of stainless steels subjected to hot forging and observed that microstructural refinement significantly improved the erosion resistance of the steel [13]. Similarly, investigated slurry erosion of steel in the mining conditions and concluded that slurry velocity and slurry concentration are the most influential factors for material loss. The role of size of the abrasive particle has also been widely explored [14]. Reported that large abrasive particles tend to increase the material loss due to the higher kinetic energy associated with impact of the slurry particles. It also indicated that erosion damage becomes more severe increase in particle size and velocity [15]. In a recent study, on duplex and super stainless steels with superior mechanical properties and enhanced corrosion resistance for slurry handling applications. Reported an experimental investigation on the slurry erosion behaviour of duplex stainless steel using Taguchi optimization and artificial neural network modelling.

It is reported that that slurry velocity and particle concentration have a significant effect on erosion rate, while the angle of impingement plays an important role in determining the wear mechanism [16]. Advanced coatings and surface modification techniques has also been explored to improve erosion resistance. Examined the erosive wear characteristics of boronized martensitic stainless steel and reported that boronizing significantly enhance the hardness and reduces the erosion rate [17]. Similarly, investigated the laser-cladded stainless-steel coatings and reported significant improvement in the cavitation and slurry erosion resistance of the coated steel, due to the refined microstructures and strong metallurgical bonding between the steel and coating. Additive manufacturing and friction stir processing are also been investigated for enhancing the erosion resistance of components [18]. Studied slurry erosion behaviour of additively manufactured steel specimens and reported that optimizing the printing parameters can significantly improve the wear resistance [19]. In a study, by it is demonstrated that friction stir processing with high-entropy alloy reinforcement resulted in improved slurry erosion resistance of stainless steel through grain refinement and increase in hardness [20]. Erosion–corrosion behaviour is a much more critical phenomenon affecting the material performance in slurry environments. Fan et al. investigated erosion–corrosion characteristics of desulfurization slurry on stainless steel pipelines and found that the combined action of mechanical erosion and electrochemical corrosion significantly accelerated the material degradation. It also emphasized the importance of selection of corrosion-resistant alloys for components operating in slurry environments. Although considerable amount of research has been carried out on the slurry erosion behaviour of conventional stainless steels and duplex alloys, relatively limited attention has been given to super austenitic stainless steels such as Super 304HCu stainless steel [21]. Therefore, this investigation is necessary to better understand the slurry erosion performance of Super 304HCu alloy under different operating conditions. The current study focuses on evaluating the influence of key erosion parameters such as slurry velocity and particle concentration on the erosion behaviour of Super 304HCu.

## II. MATERIALS AND METHODS

The material used in this investigation was super austenitic stainless-steel type Super 304HCu. Rectangular specimens with dimensions of  $20 \times 30 \times 3.5$  mm<sup>3</sup> were machined from tubes, using a wire-cut Electrical Discharge Machining (EDM) process to ensure precise cutting and dimensional accuracy. After machining, the burrs and oxides present on the specimen edges were carefully removed to obtain smooth surfaces (Figure 1a). The samples were then cleaned with ethanol and subsequently dried before conducting the tests. The particle size of the abrasive particles used in the experiment were silica sand particles ranging from 0.5–1.0 mm. The slurry used for the experiments was prepared with silica sand particles suspended in demineralized water to create an abrasive medium for the test. The slurry erosion experiments were conducted using a slurry pot erosion tester, which allowed controlled circulation of abrasive slurry over the specimen surface. The schematic arrangement of the tester and the dimensions of the pot are shown in Figure 2a and 2b respectively. The specimens were securely mounted in the test chamber using bolts to ensure stable positioning during the experiment as shown in Figure 1b. The angle of impact is kept constant at 90° for all the test conditions to create normal impact conditions.

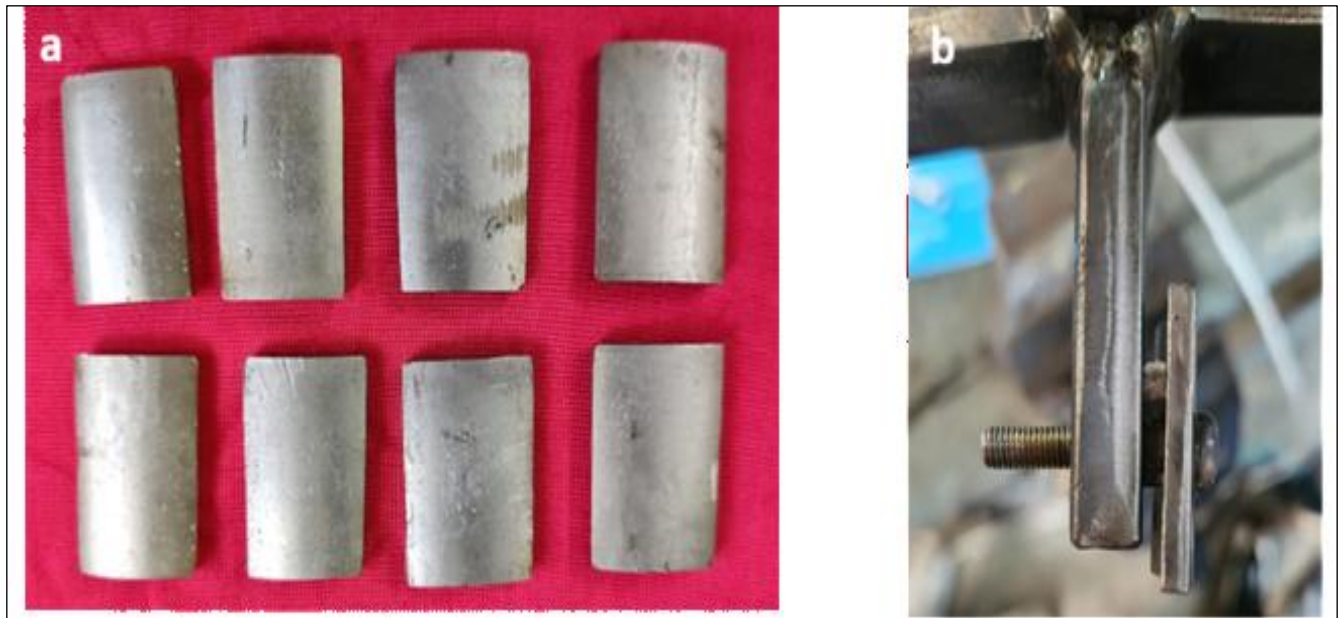


Figure 1: Photograph of (a) machined specimen and (b) specimen mounted on slurry pot test chamber.

Source: Authors, (2026).

In order to evaluate the effect of slurry velocity on Weight loss of Super 304Hcu, the erosion tests were carried out at three different rotational speeds of 1000 rpm, 1500 rpm, and 2000 rpm, (6 m/s, 9 m/s, and 12 m/s) under 30% Slurry Concentration. Similarly, to study the effect of slurry concentration, it is varied as 10 %, 20 %, and 30 % at constant speed of 1500 rpm (9 m/s). Each experiment was conducted for a total duration of 120 minutes, and the weight loss of the specimens was recorded at regular intervals of 20 minutes. The initial and final weight of each specimen was measured using a precision electronic balance. The weight loss of the specimen was calculated as the difference between the initial and final weight.

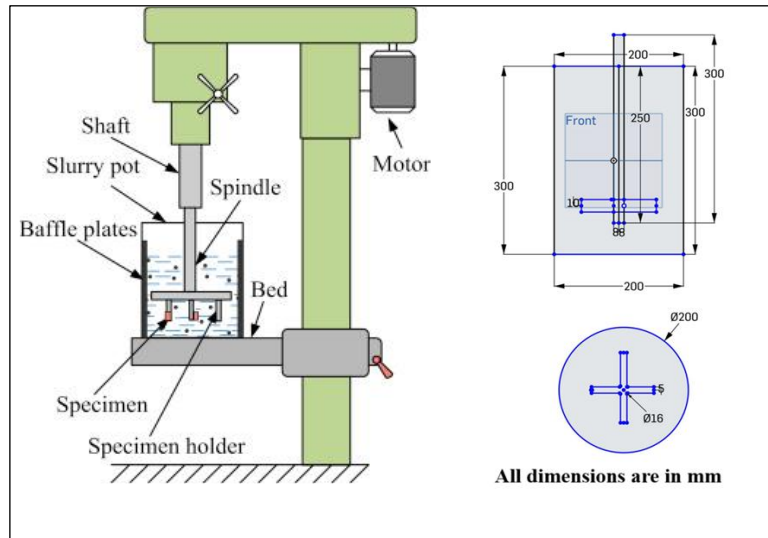


Figure 2: Schematic arrangement of slurry pot tester (a) and dimensions of the slurry pot (b).  
Source: Authors, (2026).

### III. RESULTS AND DISCUSSION

#### III.1 EFFECT OF SLURRY VELOCITY ON WEIGHT LOSS

Figure 3 shows that weight loss increases progressively with increase in both exposure time and slurry velocity. At the initial stage of the experiment, the increase in weight loss is relatively moderate. However, as the erosion time increases, the rate of material removal becomes significantly higher. This behaviour can be attributed to the continuous particle impacts that can gradually weaken the surface and accelerate erosion damage.

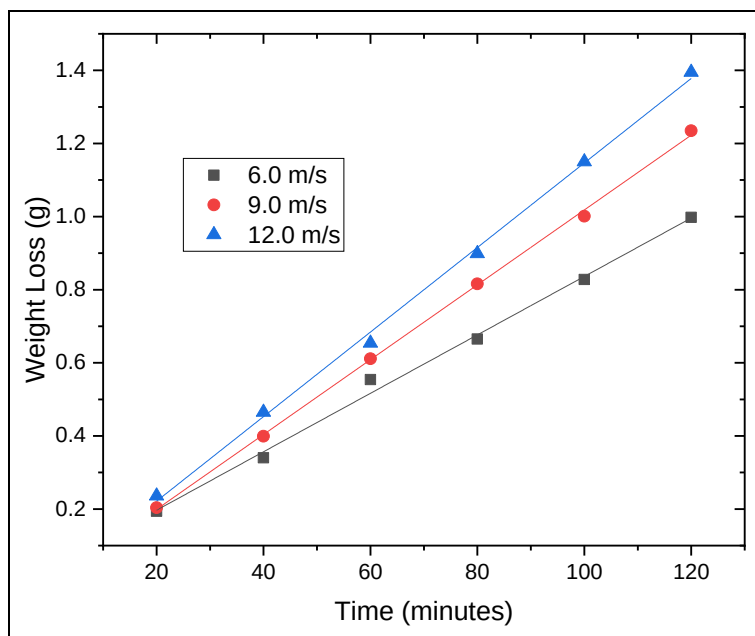


Figure 3: Variation of weight loss of Super 304HCu alloy with time at different slurry velocities (6 m/s, 9 m/s, and 12 m/s) at slurry concentration of 30 %.  
Source: Authors, (2026).

Among the three test conditions, the highest weight loss occurred at the slurry velocity of 12 m/s, followed by 9 m/s and 6 m/s. This trend indicates that the slurry velocity is one of the most influential parameters in controlling the slurry erosion wear. Higher velocity increases the kinetic energy of abrasive particles striking the material surface, and resulting in greater material removal. The observed behaviour in Super 304HCu is consistent with the findings reported by who reported that erosion rate increases significantly with increase in particle velocity due to higher impact energy of the abrasive particles [11], [12]. Similarly, also reported that the increase in the particle velocity enhances the cutting and ploughing action of abrasive particles on the surface of the stainless steel [15]. In addition, Singh et al. observed that the slurry velocity plays a dominant role in determining the erosion rate of duplex stainless steels, where higher slurry velocities can lead to more severe surface damage. It is also confirmed that the kinetic energy of impacting particles is directly proportional to the square of velocity, which significantly amplifies the erosion process. These observations confirm that particle impact energy and frequency of collisions increase with velocity, resulting in a higher erosion rate [16].

### III.2 EFFECT OF SLURRY CONCENTRATION EFFECT ON WEIGHT LOSS

Figure 4 illustrates the variation of weight loss of Super 304HCu alloy with time at different slurry concentrations (10%, 20%, and 30%). It is evident that the weight loss increases significantly with increase in the time of exposure for all slurry concentrations studied, indicating continuous material removal due to the particle impact in the slurry environment. Additionally, the rate of erosion significantly increases as the slurry concentration increases from 10% to 30%, demonstrating the strong influence of abrasive particle density on erosion behaviour.

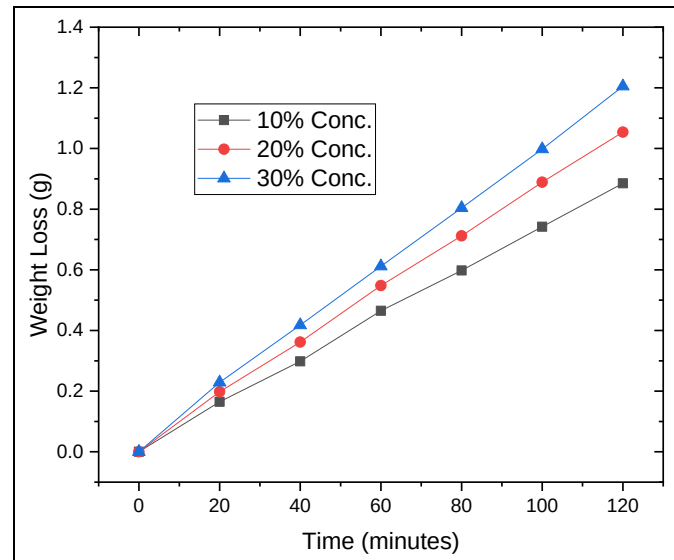


Figure 4: Variation of Weight loss of Super 304HCu alloy with time at different slurry concentrations (10%, 20%, and 30%) at constant velocity of 9 m/s.

Source: Authors, (2026).

At 10% slurry concentration, the weight loss was reported as 0.88 g after 120 minutes of erosion. This comparatively lower erosion rate is attributed to the fewer number of abrasive particles interacting with the material surface. As the slurry concentration increases to 20%, the Weight loss increase more rapidly, reaching approximately 1.05 g at 120 minutes. An increase in slurry particle concentration leads to more frequent collisions between abrasive particles and the specimen surface, which in turn increases the rate of material removal. As the concentration of particles in the slurry increases, the number of particles impacts per unit time also increases, in turn accelerating the erosion process. The highest weight loss was observed at a slurry concentration of 30%, where the value reached approximately 1.20 g after 120 minutes of testing. At higher concentrations, the slurry contains a greater number of abrasive particles, which significantly increases the frequency of particle impacts on the material surface. This results in intensified material removal mechanisms and ultimately lead to a higher erosion rate compared to lower slurry concentrations. These observations are consistent with findings that were reported in the earlier studies. Chen et al. reported that an increase in the number of abrasive particles in a slurry leads to a higher erosion rate due to the greater frequency of particle-surface interactions [15]. Similarly, reported slurry concentration as one of the most influential parameters affecting the erosion wear in stainless steels. From the experimental results it is indicated that higher particle concentrations cause increase in the likelihood of the impact events, and thereby cause higher material loss [16]. Furthermore, explained that the slurry erosion typically occurs through mechanisms such as micro-cutting, plastic deformation, and surface fatigue. At higher particle concentrations, these mechanisms become more pronounced because multiple particles interact simultaneously with the material surface, resulting in more severe erosion damage. The cumulative effect of these impacts accelerates the wear process [11], [12]. The nearly linear trend observed in the graph suggests that the erosion rate remains relatively stable throughout the test duration, although the magnitude of wear increases with slurry concentration. Similar trends were reported by Sharma et al. and Das et al. in their studies on slurry erosion of stainless steels used in mining and industrial environments. The results clearly indicate that slurry concentration plays a significant role in determining the erosion rate of Super 304HCu stainless steel. Higher particle concentration leads to increased abrasive interaction with the surface, resulting in greater material removal [13], [14].

### III.3 SEM MICROGRAPH ANALYSIS OF WORN SURFACE

Scanning Electron Microscopy (SEM) was used to examine the worn surfaces of Super 304HCu specimens after slurry erosion testing in order to understand the dominant wear mechanisms. The SEM micrographs reveal significant surface damage caused by repeated impacts of abrasive particles present in the slurry. The SEM micrographs of Figure 5 reveal several characteristic surface features associated with slurry erosion, including surface pits, and regions of plastic deformation. The presence of these features suggests that the erosion behaviour of the material is largely dominated by ductile erosion mechanisms. The increasing slope of the curves in Figure 3 also indicates that the erosion process becomes more severe over time. As the surface undergoes repeated particle impacts, micro-cracks and surface pits develop, which facilitate further material removal. Similar erosion mechanisms such as micro-cutting, plastic deformation, and surface fatigue were reported by Yilmaz et al. during the erosion testing of stainless steels. The results demonstrate that Super 304HCu alloy exhibits better resistance at lower slurry velocities, while higher velocities accelerate erosion wear due to increased particle impact energy [17]. These findings suggest that controlling slurry velocity is essential for improving the service life of components used in slurry transportation systems.

At lower slurry velocities, the eroded surfaces exhibit relatively shallow grooves with only limited surface deformation. The damage appears mild, mainly caused by the sliding and rolling motion of abrasive particles across the surface. As the particles move along the direction of slurry flow, their cutting action produces fine and nearly parallel grooves on the material surface.

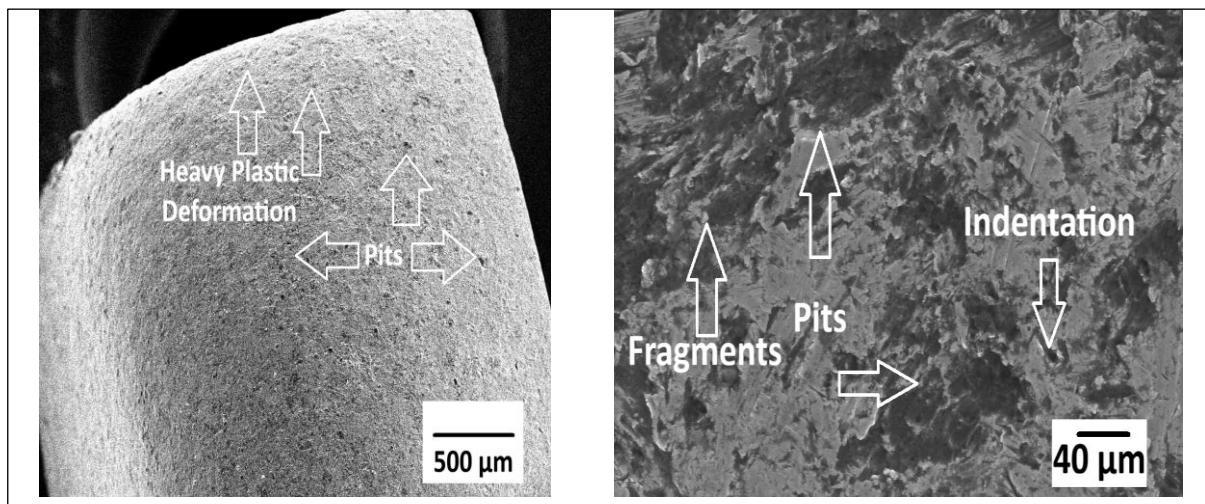


Figure 5: Scanning Electron Microscopy (SEM) micrograph of the worn surfaces of Super 304HCu (30% Concentration, velocity 9 m/s, time 120 minutes).

Source: Authors, (2026).

When the slurry velocity increases, the severity of surface damage becomes more pronounced. The SEM images show deeper grooves, larger pits, and noticeable plastic deformation in several regions of the specimen surface. This increased damage is mainly attributed to the higher kinetic energy of the impacting particles. With greater impact energy, the abrasive particles produce stronger micro-cutting actions and remove material more effectively from the surface. In addition, the presence of alloying elements such as chromium, molybdenum, and copper in Super 304HCu promotes the formation of a stable passive film on the surface. This passive layer can provide a certain degree of protection against erosion–corrosion effects. However, under continuous abrasive particle impacts, the protective film may gradually deteriorate, exposing the underlying material to further erosion damage.

#### IV. CONCLUSIONS

In this work, the slurry erosion behaviour of the Super 304HCu stainless steel is investigated at different operating conditions, such as slurry velocity, slurry concentration, and time of exposure. From the experimental results, the weight loss of the specimens increases steadily with erosion time. This confirms the continuous material removal from the specimen by the abrasive particles which repeatedly strike and slide over the specimen surface during the slurry flow. Among the parameters investigated, the slurry velocity was found to have a significant effect on the erosion rate. As the velocity increases, the extent of the material loss also increased. The maximum weight loss occurred at 12 m/s, while the lowest at slurry velocity of 6 m/s. This behaviour can be attributed to the high kinetic energy of slurry particles at higher velocities, resulting in stronger impacts and more severe surface damage. A similar trend was observed with respect to slurry concentration. Increasing the concentration of abrasive particles led to a higher frequency of particle–surface interactions. As a result, the probability of impact events increased, which in turn accelerated the erosion process and produced greater material loss. The graphical analysis supports these observations and clearly indicates that the erosion rate rises with both slurry velocity and slurry concentration. These parameters therefore play a dominant role in controlling the slurry erosion under the present experimental conditions. Further insight into the wear mechanisms was obtained from the SEM examination of the eroded surfaces. The micrographs revealed several typical features such as micro-cutting grooves, ploughing marks, pits, and regions of plastic deformation. These characteristics suggest that the erosion process is largely governed by ductile mechanisms, where cutting and plastic deformation act together to remove material from the surface. Overall, the results indicate that Super 304HCu alloy exhibits reasonable resistance to slurry erosion. However, the extent of material loss becomes significantly higher at increased slurry velocities and particle concentrations. Future studies may consider the influence of additional parameters, such as particle size, and temperature, in order to understand the erosion performance of this alloy better.

#### V. AUTHOR'S CONTRIBUTION

**Conceptualization:** M. Balachandar and M. Vinoth Kumar.

**Methodology:** M. Balachandar and M. Vinoth Kumar.

**Investigation:** M. Balachandar.

**Discussion of results:** M. Balachandar and M. Vinoth Kumar.

**Writing – Original Draft:** M. Balachandar.

**Writing – Review and Editing:** M. Vinoth Kumar.

**Resources:** M. Balachandar and M. Vinoth Kumar.

**Supervision:** M. Vinoth Kumar.

**Approval of the final text:** M. Balachandar and M. Vinoth Kumar.

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