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ABRASIVE WEAR OF MEDIUM CHROMIUM Fe-Cr-C HARDFACING ALLOYS

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ABSTRACT

Weld deposits are one of the most used economical ways of the wear resistance increase. The study compares the characteristics of the hardfacing material welded-on base material and investigate the abrasive wear resistance. The research has been carried out using hardfacing alloys reinforced with primary chromium carbides and complex carbides. The hardfacing material was deposited on the Mild steel using shielded metal arc welding (SMAW) process.. Two different commercial hardfacing materials were studied in terms of the microstructure effect. The abrasion wear testing was carried out in a dry sand-rubber wheel abrasion machine according to the procedure A of ASTM G65 standard. The microstructure characterization and surface analysis were made using optical and scanning electron microscopy. The results illustrates that a significant effect of primary carbides on the abrasive wear resistance of hardfacing deposits.

Keywords: Abrasive wear resistance; Carbide; Hardfacing alloys; Microstructure characterization; Wear mechanism .

I. INTRODUCTION

Fe-Cr-C alloys are used in several conditions where extreme erosion occurs and therefore the abrasion resistance is necessary[1]. Their exceptional abrasive and erosive wear resistance results primarily from their high volume fraction of hard carbides, though the toughness of the matrix also contributes to the wear resistance.

The investigations of Fe-Cr- C alloy microstructures have shown that these types of materials have hypoeutectic, eutectic, and hypereutectic structures[2][3]. M7C3 primary carbides form in large amounts at higher carbon concentrations. These types of microstructures possess good wear resistance properties[5].

This kind of hard material can be represented by medium chromium white cast iron, with an extremely high hardness value of M7C 3 (about 418 HV0.5). M7C3 is surrounded by austenite, which is relatively soft compared to M7C 3, so a crack will spread along the interface between austenite and M7C3.

Medium chromium content Fe-Cr-C hardfacing alloys can also be used commercially for such components that are designed to endure harsh abrasive conditions[4]. The massive carbides present in the microstructure are M23C6. These can be described as composites with large and hard carbides in a softer body centered cubic Cr-Fe alloy matrix. If medium chromium content (Fe -Cr-C) hardfacing alloys are in hypereutectic, i.e. primary M23C6 is surrounded by the Cr-Fe and M23C6 eutectic structure, they will reduce the occurrence of the crack, because the lamellar eutectic structure will resist crack spreading along the grain boundary.

Hardfacing is a commonly employed method to improve the surface properties of components of earthmoving equipments, agricultural tools, the components for mining operation, soil cultivation equipments, and others to extend the service life of components. An alloy is homogenously deposited onto the surface of a soft material (usually low or medium carbon steels) by welding, with the purpose of increasing the hardness and wear resistance without any significant loss in ductility and on the Toughness of the substrate. A wide variety of hardfacing alloys are commer-cially available for the protection against wear[6]. De-posits with a microstructure composed by dispersed carbides in austenite matrix are extensively used for abrasion applications and are typically classified ac-cording to the expected hardness. Nevertheless, the abrasion resistance of a hardfacing alloy depends on many other factors such as the type, shape, and distribution of hard phases, as well as the tough-ness and strain hardening behaviour of the matrix[7]. Chromium- rich electrodes are widely used due to their low cost and availability, however, more expensive tungsten or vanadium-rich alloys offer, a better performance due to a good combination of hardness and toughness. Complex carbides elec-trodes are also used, especially when the abrasive wear is accompanied by other wear mechanisms.

The technology of surfacing comprises oxyacety-lene gas welding (OAW), gas tungsten arc welding (GTAW) or tungsten inert gas welding (TIG), submerged arc welding (SAW), plasma transferred arc welding (PTA), gas metal arc welding (GMAW) [11].

Table 1. Deposition rates of different welding processes

Process	Deposition Rates (Kg/hr)
Flux core arc welding (FCAW)	3.63-11.34
Gas metal arc welding (GMAW)	2.3 -5.44
Gas tungsten arc welding (GTAW)	1.4 - 2.3
Shielded metal arc welding (SMAW)	1.4 -2.3
Submerged arc welding (SAW)	3.63 -11.34
Oxy fuel arc welding (OFW)	2.3 - 4.54

II. EXPERIMENTATION

A. HARDFACING WELDING PROCESSES

The most common welding processes for hardfacing are shielded metal arc welding (covered electrode), flux cored arc welding and submerged arc welding. Although other processes such as oxy fuel and gas tungsten arc can be used, their low deposition rates are limited in some applications. The welding processes named shielded metal arc welding (SMAW) was selected for this study.

B. TEST SPECIMAN PREPARATION

i) BASE METAL

The selection of base metal is very essential in deciding what alloy to use for hardfacing deposit. Since welding procedure differs according to the base metal. The base metal selected for this study is Mild steel which composes the main elements of carbon, silicon, manganese, sulphur, and phosphorous and ferrous. The chemical composition is shown in Table 2.

Table 2 Chemical composition of base metal (In weight percentages)

C	Si	Mn	S	p	Fe
0.18	0.32	1.47	0.013	0.029	Bal

C. HARDFACING ALLOY

Two different commercial hardfacing alloys were used for overlaying. These alloys were selected due to its low cost and easy availability in the local market and suitability for the service condition (low stress abrasion). They are basically iron – based alloys [12] having varying amount of chromium, carbon, silicon and other alloying elements as they are more suitable for shielded metal arc welding process. Chemical compositions of two electrodes are presented in Table 3.

Table 3 Chemical composition of hardfacing alloy (In weight percentages)

Electrode	C	Si	Mn	S	p	Cr	Mo	Ni	V	Fe

Hardfacing 1	0.33	0.28	1.15	0.014	0.025	2.22	-	-	-	Bal
Hardfacing 2	0.1	0.38	1.51	0.024	0.03	2.15	0.745	1.09	0.103	Bal

D. WELDING CONDITIONS

The standard size test specimens of 16 nos. with the dimensions of 250×100×12 mm were selected for the experiment.

The following precautions are taken before hardfacing.

- The electrodes are perfectly dried in the furnace and baked at 250° C one hour before the use
- Area of the weld is properly cleaned
- Preheated the hardfacing area to a minimum of 200° C

E. MACHINE SPECIFICATIONS

Name: TORNADO MIG 630 Arc welding machine
Current: 100-630 A
Input Voltage: 415 V ± 10% / 50-60 Hz / 3 Phase
Machine Capacity: 50KVA

III. METHODOLOGY

The experiment was carried out in three stages to investigate the effect of current, travel speed and voltage on hardfacing electrodes, and the corresponding hardness was determined.

(i) In first stage, voltage (V) and travel speed (S) were kept constant and current (A) was increased.
(ii) In second stage, voltage (V) and current (A) were kept constant and travel speed (S) was increased.
(iii) In third stage, current (A) and travel speed (S) were kept constant and voltage (V) was increased.

A.Stages of Experiment

Table 4 Varying current

Electrode	Current (A)	Voltage (V)	Travel Speed (cm/min)	Hardness (HV 0.5)
Hardfacing 1	200	25	23.1	380
	250	25	23.1	318
	300	25	23.1	317
Hardfacing 2	180	25	23.1	370
	200	25	23.1	416
	250	25	23.1	330

Table 5 Varying travel speed

Electrode	Travel speed (cm/min)	Voltage (V)	Current (A)	Hardness (HV 0.5)
Hardfacing 1	15.0	25	200	417
	21.4	25	200	418
	50.0	25	200	356
Hardfacing 2	16.67	25	200	377
	25.0	25	200	388
	50.0	25	200	406

Table 6 Varying voltage

Electrode	Voltage (V)	Current (A)	Travel Speed (cm/min)	Hardness (HV 0.5)
Hardfacing 1	15	215	37.5	537
	25	215	37.5	390
Hardfacing 2	15	215	37.5	401
	25	215	37.5	357

The selected standard size of the test specimen is shown in figure 1.The results of hardfacing obtained by varying current, travel speed and voltage along with their hardness and the corresponding relationship between them are shown in figures 4, 5 and 6 respectively. From graphs, it is concluded that as current, travel speed and voltage increases the hardness of surface and the layer next to the surface decreases. Figure 2 shows that, as current increases the hardness of the bead and HAZ decreases. Figure 3 shows that, as travel speed increases the hardness of the bead and HAZ decreases. Figure 4 shows that, as voltage increases the hardness of the bead and HAZ decreases.

Figure 1. Standard test specimen of size 75mmX 26mmX6mm

A. Dry Sand Abrasive Wear Test

In the present study, sample of 75x26x6 mm size were used for testing as shown in figure 1 as per ASTMG65 standards. Specimens were ground using surface grinder to make the surface flat. Before the abrasive wear test all the specimens were cleaned with acetone and then weighed on an electronic balance with an accuracy of ± 0.1 mg. The three-body abrasive wear tests were conducted using a dry sand/rubber wheel abrasion tester as per ASTM G65-04 (2010) . The sand particles of AFS 60 grade were used as abrasives and they were angular in shape with sharp edges. The sand particles were sieved (size200–250 µm), cleaned and dried in an oven for 6 hr at 40 ^{0}C. In this test, samples were held against a rotating rubber wheel under the constant flow of abrasives in between the sample and the rubber wheel under predetermined load. The actual photograph of the testing machine is shown in figure7.

B. Test Conditions

Speed: 200 ± 5 rpm

Sample test duration: 15 and 30 min.

Abrasive: loose silica sand having particle size 200 - 250µm.

Load is kept constant at 130.5 N for all the samples. After each test, the samples were cleaned with acetone and then weighed on the electronic balance. The wear loss was calculated as weight losses in gms. Sample of 26x75x6 mm size were used for analysis. Specimens were ground using surface grinder to make the surface flat. Dry sand abrasive wear test was carried out as per ASTM G65 standards. In this test, samples were held against a rotating rubber wheel under the constant flow of abrasives in between the sample and the rubber wheel under predetermined load. The wear testing machine is shown in figure 7 and the test conditions are given here under:

Speed: 200±5rpm

Sample run duration: 30 minutes

Abrasive: loose silica sand having particle size 200 to 250 µm

Silica sand of size between 200 to 250µm was used as abrasive. Load is kept constant at 130.5N for all the specimens. The wear rate was calculated as weight loss in gms. Results indicate that as hardness increases, the loss of wear decreases. Electrode-I has less wear as compared to electrode-II as the percentage of chromium, carbon and silicon is more in electrode-I. However the composition of chromium, carbon & silicon in the weld deposit made with type-I electrode is higher than that of weld deposit made with type-II electrode. Higher amount of chromium, carbon, silicon and finer structure resulted in higher hardness where as lower hardness values were recorded in weld deposit with less amount of Cr, C & Si & coarser structure. From wear testing data under various conditions of the parameters, it can be stated that weld deposits made with type I electrode are more wear resistant than the weld deposits made with type II electrode.

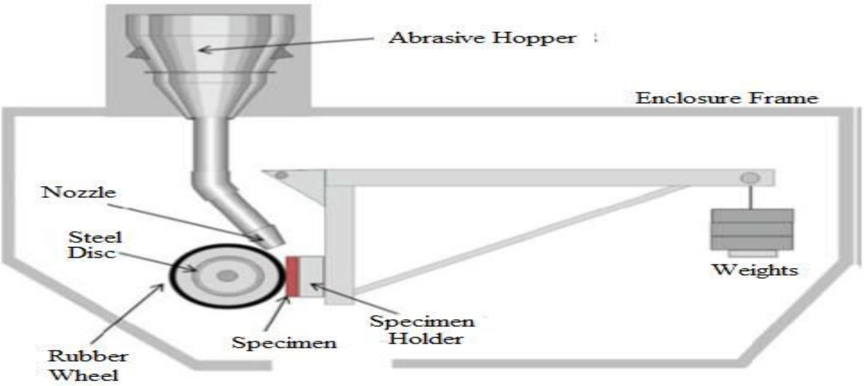

Figure 2(a): Dry Sand/Rubber Wheel Abrasion Tester

Figure 2(b): SEM Picture of Silica Sand (200-250 µm)

IV. MICROSTRUCTURE AND HARDNESS

The characterization of microstructure has been done with optical microscopy after etching with 5 vol % alcoholic nitric acid. Typical microstructures of the welded deposits are shown in figures 3(a), 3(b),3(c) and 3(d) respectively.

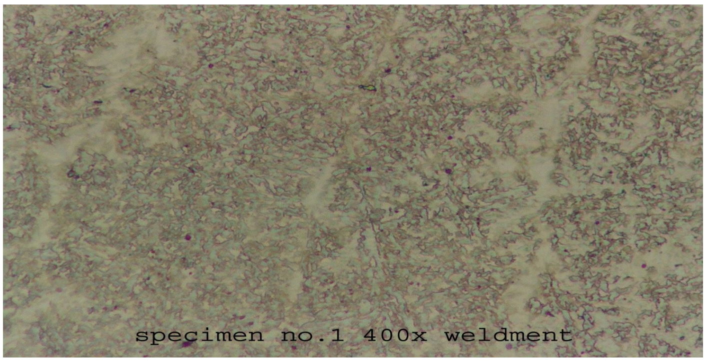

Figure 3 (a) Specimen No. 1 400x weldment

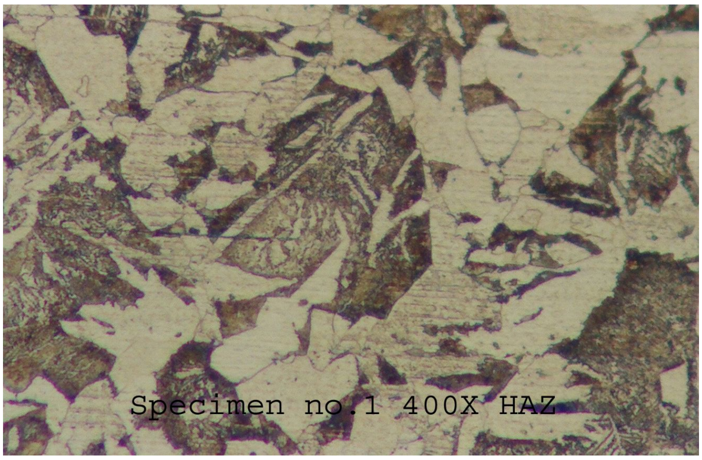

Figure 3 (b) Specimen No. 1 400x HAZ

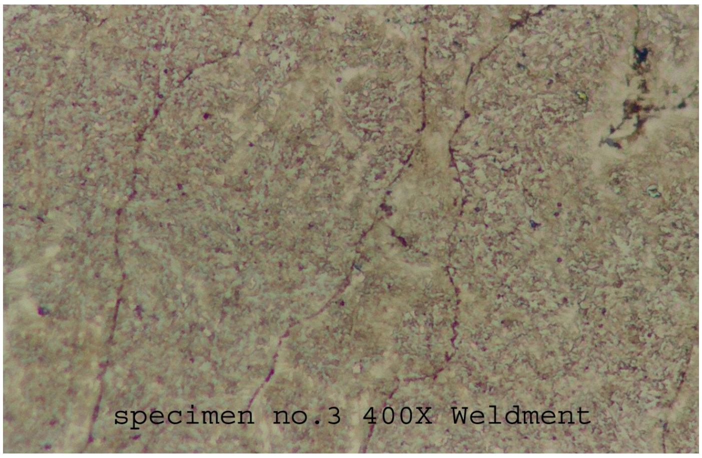

Figure 3 (c) Specimen No. 3 400x weldment

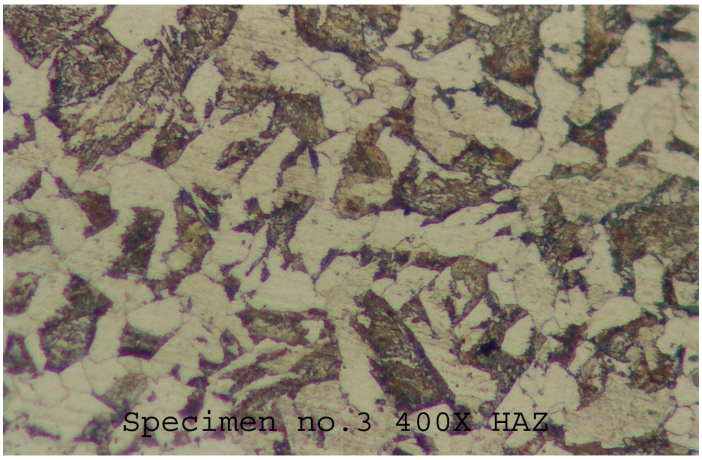

Figure 3 (d) Specimen No. 3 400x HAZ

V. MICROSTRUCTURES OF DIFFERENT HARDFACING DEPOSITS

The microstructures of low, medium and high wear resistance specimens are shown in figures 4 (a) and (b), figures 4(a) and (b) and figures 4(a) and (b) respectively. In figure 4(a) and (b), the amount of ferrite and Pearlite is more hence resulting in lower hardness and wear resistance. In figure 4 (a) and (b) the amount of ferrite and pearlite is medium hence moderate hardness and wear resistance. In figure 4 (a) and (b), the structure consists of martensite with retained austenite and patches of pearlite distributed uniformly.

The wear resistance is in fact proportional to the volume fraction in hypoeutectoid Steels [3]. Furthermore, the original orientation of the colony and the mean inter lamellar spacing have effects on wear resistance [5]. Several authors investigated that the relationship between wear resistance and hardness is affected by microstructure [4, 5, 6]. Wear resistance increased in the structural sequence from spheroidite to pearlite and from tempered martensite to bainite [3, 7]. Microstructure shows pearlite with subsequent formation of interdendritic carbides (fig 4(a) and (b)). However, the carbide content in the weld deposit made with welding parameters at current 200A, travel speed 21.4cm/min and voltage 25V is higher than that with weld deposit made with welding parameters at current 300A, travel speed 23.1 cm/min and voltage 25V (fig 4(a) and (b)) for the same electrode. Furthermore coarser microstructure are observed in weld deposit made with higher heat input at higher amperage current and travel speed for the same electrode keeping more or less similar microstructural constituents. These microstructural characteristics are also reflected in the hardness values Higher amount of carbide and finer structure, in general resulted in higher hardness, whereas lower hardness values were recorded in weld deposits with less amount of carbides and coarser structure. Several Authors [8, 9] have suggested that abrasive wear resistance increases in direct relationship with the volume of the hard constituent. It is interesting to note that weld deposits made with high heat input with higher amperage of current for the same alloy system possess higher wear resistance. Apparently one would expect lower wear resistance in the weld deposit made with high heat input, due to lower hardness value. Alloy mainly martensitic with some islands of austenite. Chromium Carbides are well distributed throughout the micro section (specimen 5, 8, 12). (Ledeburitic matrix). Major importance is an increasing resistance about abrasion due to their higher hardness and free from defects. The distribution of hard phases in the specimen 7 is quite uniform. These is a higher density of original carbides close to the fusion line, whereas at the surface only rests of carbides are visible. While observing the microstructure of all the 16 specimens, specimen 3, 4 and 7 were having defects noticed through optical microscope on the weld surface deposit. Specimen no. 3 which contains network of grain boundary cracks and several blow holes. Specimen no. 4 having several blow holes observed within the weldment. Specimen no. 7 having microcracks within weldment.

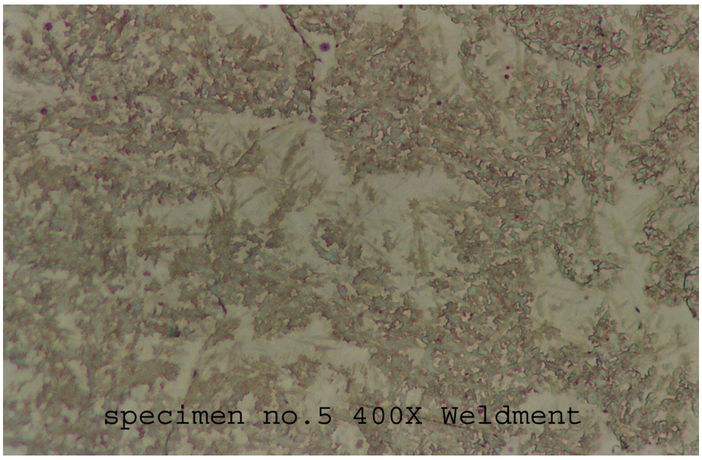

Figure 4 (a) Specimen No. 5 400x weldment

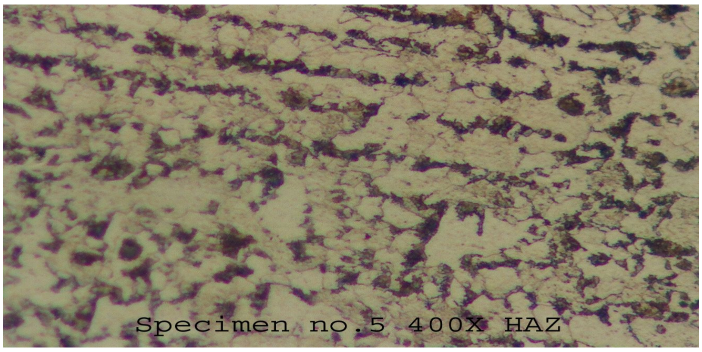

Figure 4 (b) Specimen No. 5 400x HAZ

Alloy (hardfacing 1) is the main martensitic with some kinds of austenite. Fine primary chromium carbides are well distributed throughout the micro section. The hardness on the Weldment and HAZ towards the base metal has been surveyed for every 0.5 mm depth and the values are plotted in figure 4.1.

The chemistry of the Fe/Cr carbides is reported for hypereutectic FeCrC alloys in literature to M_7C_3 structure [12-14]. The hardness values of the ledeburitic matrix which are determined to about 500 HV 0.5 are close to previous investigations from Fischer [1] and Buytoz [2]. Beside small and evenly distributed primary chromium carbide at a volume content of approximately 5% can be detected which are supposed to be of major importance for increasing the resistance against abrasion due to their high hardness. While observing the alloy of hardfacing 2 the constituents of primary chromium carbides are not well distributed throughout the micro structure. After the dry sand abrasion test comparisons were made between electrode 1 and electrode 2, the electrode 1 is more wear resistance than electrode 2.

A closed net or skeleton of brittle Fe/Cr carbides is clearly surrounds the primary dendrites. Higher welding amperage, higher arc travel and higher voltage leads to decreasing hardness. Overall the chromium carbides are irregularly distributed. There is a higher density of original carbides close to the fusion line, whereas at the surface only rests of carbides are visible. BAIRD spectroscope is used to analyze the microstructure of the specimens. Cross sections of the weld were polished and etched with kalling's and Nital 2%. Different types of carbides present in the microstructures were first identified on the basis of their morphologies and confirmed by micro hardness measurements.

VI. CONCLUSION

1. Hardfacing materials may be deposited by a wide range of welding processes, and their properties depend strongly on the welding procedure and conditions used. For example, the arc voltage and current have a significant influence in determining the deposit geometry.
2. Although an increase in these variables leads to the formation of wider and taller deposits, other parameters such as the arc polarity, the travel speed, and preheat are also found to affect weld bead geometry.
3. The heat input, which is a function of the arc current, voltage and the travel speed, is found to increase the weld bead area. An understanding of the effect of the variables which influence the penetration depth is particularly important for hardfacing alloys since the level of dilution is determined by the degree of penetration. Ideally, dilution should be kept to a minimum in order to optimize the properties of the hardfacing material.
4. Results have shown that the penetration increases with the arc voltage and current, and decreases with the travel speed. The hardfacing material is mixed with the molten base metal during welding leading to a certain degree of dilution. An increase in the arc current, and the voltage gave rise to a high level of dilution, as expected. However, the arc polarity was found to play a significant role. For instance, the dilution was found to decrease with increasing the arc current when the direct current electrode negative technique was applied.
5. This is because the deposition rate of the electrode is increased leading to a high deposition rate and therefore less dilution. The microstructure of hardfacing alloys is primarily influenced by the dilution since the mixing of the original material with the base metal changes the composition, and consequently the properties. As an example, the wear resistance in increasing chromium, carbon and manganese in the hardfacing alloys was found to decrease with increasing dilution. So, for a given electrode, the welding parameters should be chosen to provide the best possible microstructure for any given application.
6. The result of the experiment clearly indicates the influence of welding parameters on hardfacing materials. The optimum values for various parameters are: Current- 200A, Travel speed- 25cm/min, Voltage- 15V.

7. Two-layer complex carbide deposits showed the best abrasive wear resistance of all the tested hard-facing alloys. In the studied hardfacing materials, the M_7C_3 carbides are of the decisive influence on the abrasive wear resistance.
8. These carbides are an effective barrier against the abrasive particle advance. Microcutting by abrasive particles was the dominant mechanism of wear.

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