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CORROSION PROPERTIES OF STRUCTURED SHEET METALS IN SALT ENVIRONMENT

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Abstract: *In the present paper the corrosion properties of structured sheet metals were investigated. The aim of this work is to determinate the influence of the structuring process on the corrosion resistance of sheet metals. For this purpose, these sheets were examined by accelerated tests in corrosion chamber. The investigation was carried out using salt spray test. The experiment was conducted for the low carbon steel DC04 in 5% NaCl environment. As a measure of corrosion damage, the weight loss was taken. The experiments point out that the steel weight loss is increasing appreciably with duration of the corrosive environment exposure. The results are presented for structured and smooth sheet metals as reference. A clear effect of the structuring process on the corrosion behaviour was observed. The results of the salt spray test show that structured sheet metals have a higher corrosion rate than smooth sheet metals. Structured sheets at the structure location "positive" have a lower corrosion rate than at the structure location "negative". The difference of corrosion properties between structured and smooth sheet metals is becoming increasingly apparent with advancing corrosion process. The regression models were developed for the weight loss rate as function of exposure time. Furthermore, the thickness reduction of structured and smooth sheet metals was calculated.*

Keywords:
– corrosion
– structured sheet metal
– salt spray test
– low carbon steel

1. INTRODUCTION

Structured sheet metal is a pre-formed material with three-dimensional geometry. Such sheet metals are applied in automobile industry as workpiece for car body components [1] and for plate girders in civil industry [2]. Structured sheet metals have higher stiffness properties in comparison to smooth sheet metals [3]. As a result, material thickness and construction weight can be reduced.

The corrosion resistance of smooth sheet metals of low carbon steels was studied in several works [4, 5]. Pre-deformation of the material has an influence on the corrosion properties [5, 6, 7] and may affect also the corrosion behaviour of structured sheet metals. Furthermore, the sheet geometry has an effect on corrosion properties [5]. For investigation of relative corrosion resistance of sheet metals, the salt spray test is usually employed [8, 9]. The advantage of this test is the comparatively short experimental time caused by the accelerated corrosion process. By the salt spray test the samples are arranged in the corrosion chamber with corrosive environment. The specimen surfaces are covered with salt water film during the experiment. In this case, the low carbon steels corrode by general corrosion type. For quantitative analysis of this corrosion damage, the weight loss and the thickness reduction are determined [8, 9]. The weight loss can be estimated from experimental measurements of sample weight before and after the test. The weight loss rate is calculated by the equation [10]:

$$\upsilon = \Delta m/(At) \tag{1}$$

In this equation υ is the weight loss rate in g/m²h, Δm is the weight loss in g, A is the corrosion area in m², t is the exposure time in h.

The thickness reduction and the corrosion rate are calculated by equations according to the standard [10]:

$$\Delta s = \Delta m/(A\rho) \tag{2}$$

$$\omega = \upsilon/\rho \quad (3)$$

In these equation Δs, the thickness reduction is expressed in mm, ρ is the low carbon steel density in g/cm^3 and ω is the corrosion rate in mm/year.

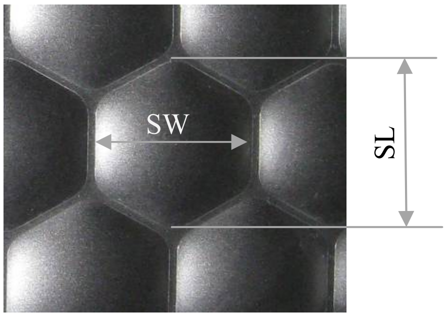

Figure 1. Sheet metal with hexagonal structure

In this work the structured sheet metal with hexagonal structure was studied, which is manufactured by hydroforming process [3, 11]. Figures 1 and 2 show the overview and the main geometrical characteristics of the structured sheet metals. The structure dimensions are 33 mm width (SW), 36 mm length (SL) and 3.1 mm height (SH). The width of the bridge area between the regular bumps is 2 mm (BW).

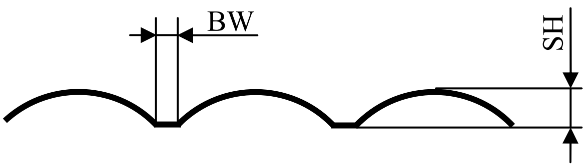

Figure 2. Geometrical characteristics of the structured sheet metal

The corrosion behaviour of structured low carbon steel sheets was examined by salt spray test and compared to results obtained for smooth sheets. The corrosion properties of structured sheet metal at the structure locations “positive” and “negative” (s. Figure 3 b) and c)) were also determined. The purpose of this work is to study the influence of structuring process on the corrosion resistance. Furthermore, the geometry effect on the corrosion behaviour of sheet metals was investigated.

2. EXPERIMENTAL WORK

2.1. Material

In this work the low carbon steel DC04 was studied. The chemical composition and the mechanical properties are presented in the Table 1 and 2 respectively.

Table 1. Chemical composition for the steel DC04

Chemical composition, [%]				
C	Mn	Si	P	S
0.033	0.19	0.006	0.008	0.006

The steel sheets were tested in different states: smooth and structured at sheet metal structure locations “positive” and “negative”. The structure location “positive” means the bumps are directed upwards. By the structure location “negative” the bumps are directed downwards.

Table 2. Mechanical properties for the steel DC04

Yield stress, $R_{p0.2}$, [MPa]	Tensile strength, R_m, [MPa]	Elongation, A_{80}, [%]
172	297	47

Figure 3 shows the samples before the experiments. The dimensions of the specimens are 150x100x0.7 mm. They were cleaned with petroleum and ethanol. The surface areas of the samples were without damages.

The corrosion test was performed on one side while the back side of the samples was insulated by an adhesive tape. The surface area of 5 mm from sheet metal edges was also protected to neglect the effect of the cutting process of the samples. It is expected that the corrosion properties on the edge area are different to the samples’ inner surface. The area of the resulting specimens test surface was 126 cm^2. For structured sheet metal the projected area is determined.

2.2. Salt spray test

A salt spray chamber with 1000 litre volume model CCT 1000-S MF made by VLM GmbH was used for the experiment. The test was performed according to the specification [12]. The standard method of the neutral salt spray test was selected.

a)
b)
c)

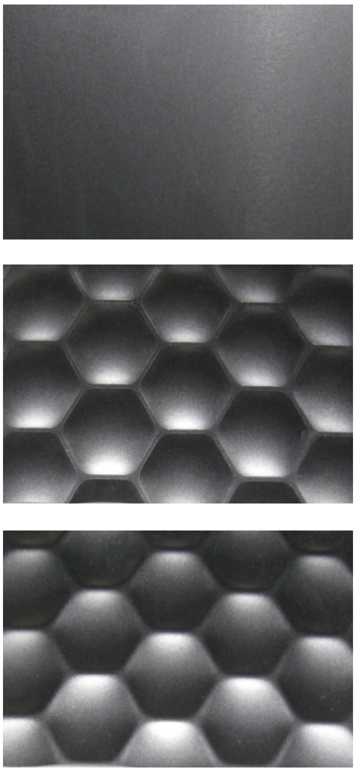

Figure 3. Corrosion samples 150x100x0.7 mm; a) smooth sheet metal; b) structured at the sheet metal structure location "positive"; c) structured at the sheet metal structure location "negative"

The initial electrolyte was 5% sodium chloride solution with pH 6.7. The collected electrolyte in the chamber during the test had a pH from 6.8 to 7 (at 25 °C). The test was carried out at the temperature of 35 °C. The samples were placed in the chamber at an angle of 80° (Figure 4).
The total duration of the experiment was 408 h. The specimens were investigated after 72, 96, 168, 264 and 408 h of the corrosive environment exposure. After each time period, 15 samples were taken out, 5 samples per each sheet metal states according to Figure 3. At first, the visual analysis was performed for the valuation of the corrosion damage. For the weight measurements these specimens were cleaned. The cleaning process consists in rough washing with water and brush. After that the corrosion products were removed by 10 min dipping in hydrochloric acid solution. Then the samples were rinsed with ethanol and dried.

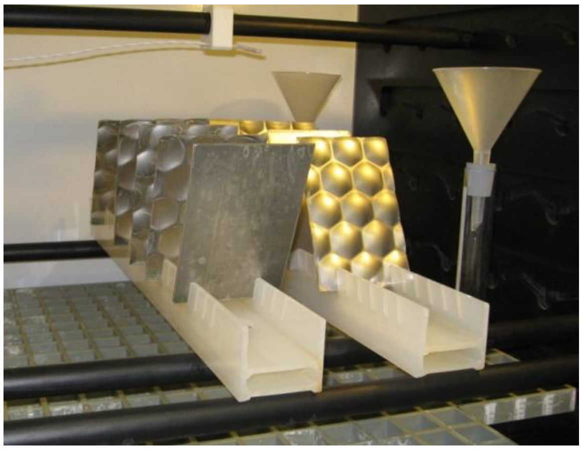

Figure 4. Samples of the sheet metal in the salt spray chamber

3. RESULTS AND DISCUSSION

Visual estimation of the sample surfaces detected, that the corrosion process of structured sheet metals progresses uniformly exactly like the corrosion process of smooth sheet metals. No preferred positions on the sample surfaces of structured sheet metals were observed. Figure 5 exemplary illustrates the sheet metals after diverse time periods of the salt spray test. Major changing of the specimen surfaces can be noticed after 72 h. At the beginning, the differences in surface view between structured and smooth sheet metals are not significant. It is evident that structured sheet metals have less corrosion products. After 168 h, the surfaces of structured and smooth sheet metals were exactly equal. With advancing time an increase of the corrosion products on the sample surfaces was observed. It is clear to see, that structured sheet metals have certainly more corrosion products after 408 h. The difference between structured sheet metals at the structure locations "positive" and "negative" could not be detected.
After the cleaning process the specimen surface were inspected again. Figure 6 demonstrates that all samples of smooth and structured sheet metals have the same corrosion type. The surfaces of the specimens have equal corrosion damages. With duration of exposure time, the deepness of the damages was increased. The structured sheet metals show clearly more damages after 168 h in comparison to smooth sheet metals. After 408 h the corrosion damages on structured samples were deeper than on smooth sheets.
The visual analysis of the sample surfaces with and without corrosion products revealed that structured

sheet metals have apparently more corrosion products and damages. With advance of the test time the difference between structured and smooth sheet metals became more significant. This leads to conclusion that structured sheet metals corrode slightly faster than the smooth ones. Further investigations confirmed this observation.

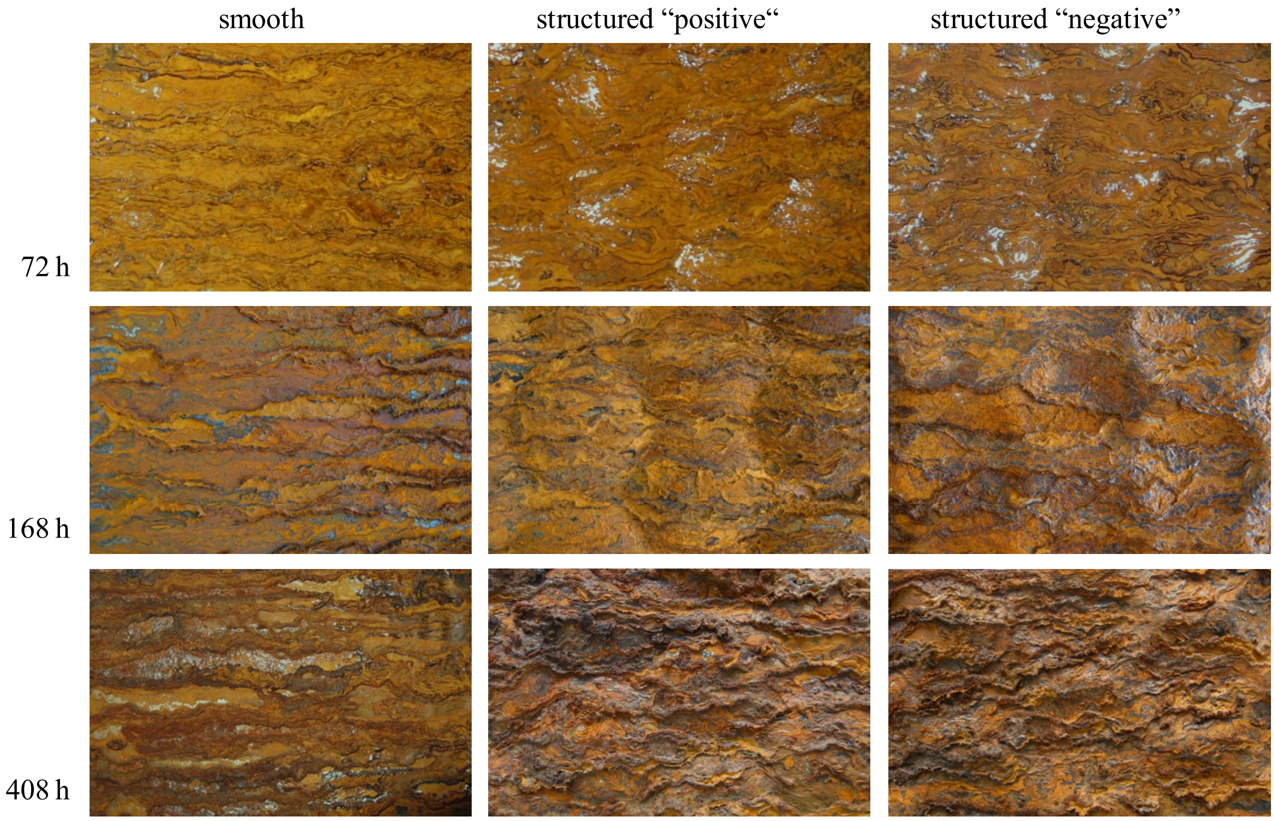

Figure 5. Specimen surfaces of sheet metals with corrosion products after 72 h, 168 h and 408 h of the corrosive environment exposure

The propagation of the corrosion was estimated by measuring of the specimen weight loss after 72, 96, 168, 264 and 408 h of the corrosive environment exposure. The process of the corrosion is characterised by different weight loss rates which were calculated according to the equation (1) for structured sheet metals at the structure locations “positive” and “negative” and smooth ones for all time periods. The average weight loss rates for smooth and structured sheet metals at the structure locations “positive” and “negative” are 1.42, 1.54 and 1.59 g/m²h respectively.

Figure 7 presents the weight loss as function of exposure time for structured and smooth sheet metals. The figure clearly shows that the weight reduction can be described by linear functions. The equations were determined for structured sheet metals at the structure location “positive” and “negative” and smooth ones for all investigated cases. They are presented on the graph. The estimated equations have a high coefficient of determination R^2 which shows their good accuracy. The slope gives quantitative comparative characteristics for weight loss rate of structured sheet metals.

Further, the thickness reduction was calculated from the weight loss of the samples and the density of low carbon steel according to the equation (2). The results are shown in Figure 8. The diagram indicates the thickness reduction of structured and smooth sheet metals after several time periods. It can be clearly seen that the thickness reduction of structured sheet metals is higher for all periods of test, even if the thickness reduction difference is almost unperceivable at the beginning. After 72 h and 96 h the difference is about 4%. With increasing test time the difference between structured and smooth sheet metal is becoming more significant.

After 168 h the thickness reduction of sheet metals increases. Also, the difference between structured and smooth sheets increases. However, the difference, between structure locations is very small. Differences in thickness reduction between structured sheet metals at the structure locations “positive” and “negative” can be clearly observed only after 264 h.

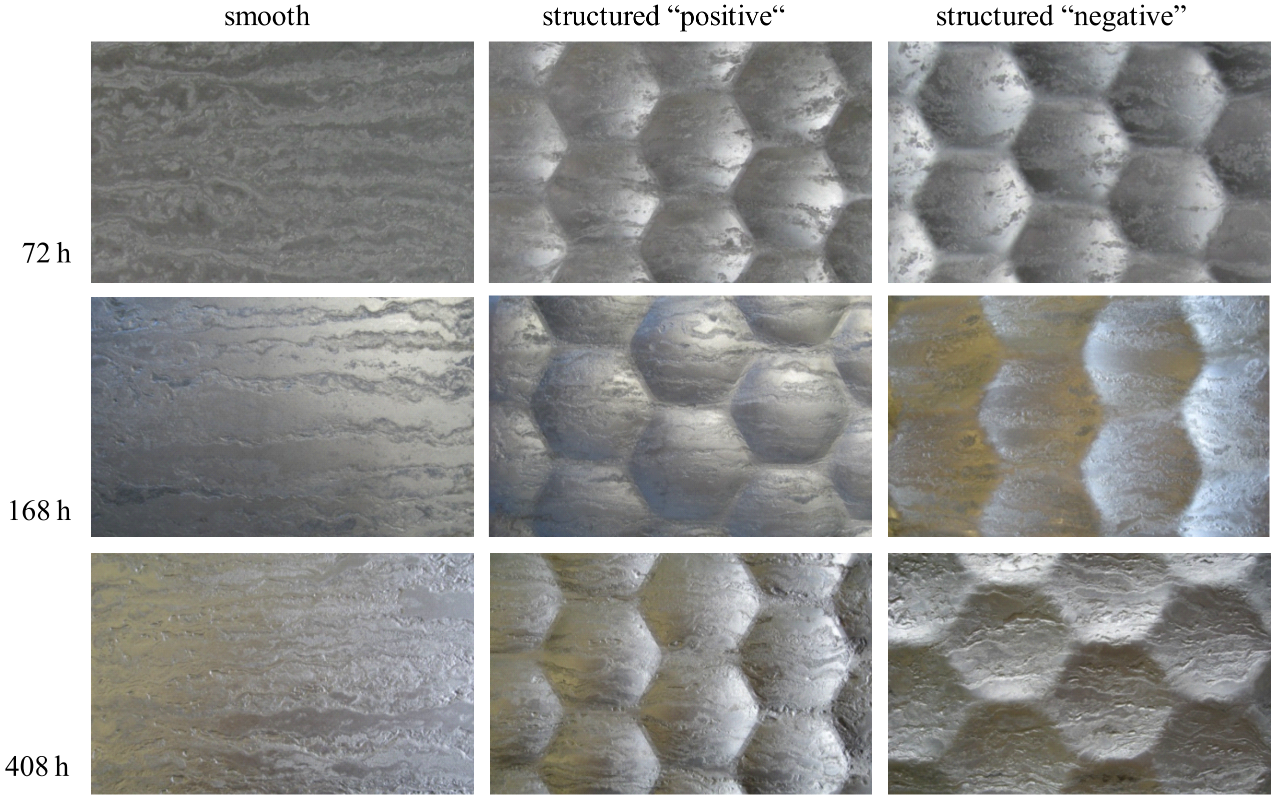

Figure 6. Cleaned specimen surfaces of structured at the structure locations “positive” and “negative” and smooth sheet metals after 72 h, 168 h and 408 h of salt spray test.

After 408 h the difference of thickness reduction between the smooth and structured sheet metal at the structure location “positive” is 8.7% and 8% between structure locations “positive” and “negative”.

For further investigation, the corrosion rate has been calculated according to the equation (3) from the average of the weight loss rate. This is the main characteristic for the determination of corrosion properties. The diagram in Figure 9 presents the corrosion rate for structured and smooth sheet metals, which indicates the corrosion resistance of these sheets. The corrosion rate of structured sheet metal at the structure location “positive” is 8% and at the structure location “negative” 12% higher in comparison to smooth sheet metals. Both visual estimating and performed measurements and calculations show the equal results. The structured sheet metals have lower corrosion resistance than smooth ones. The reason for the moderate degradation of their corrosion properties is the plastic deformation due to manufacturing processes. However, the effect of hydroforming is not significant. The corrosion resistance is also different between structured sheet metals at the structure locations “positive” and “negative” as reason of the geometry.

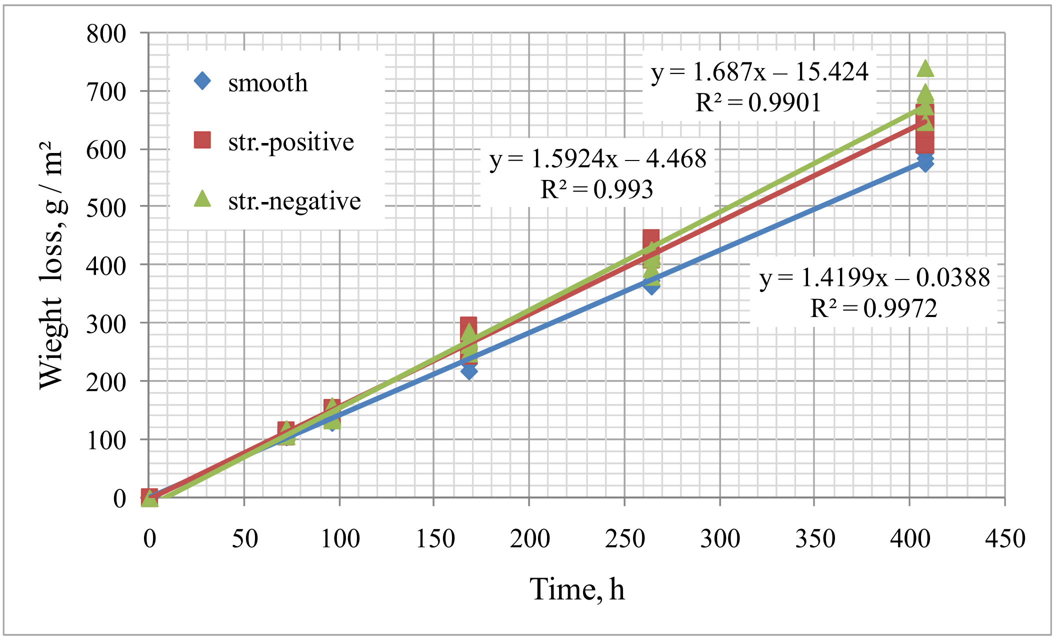

Figure 7. Weight loss rate for structured and smooth sheet metals

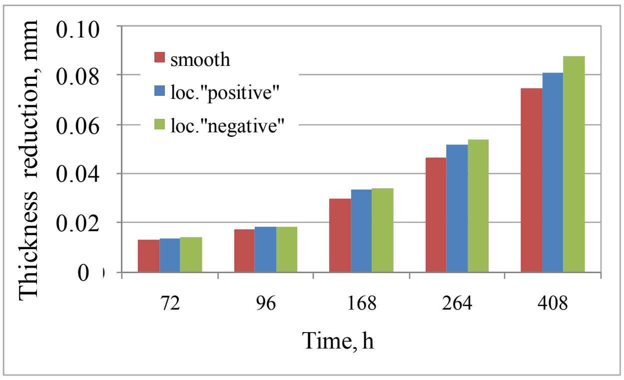

Figure 8. Thickness reduction as function of time for structured and smooth sheet metals

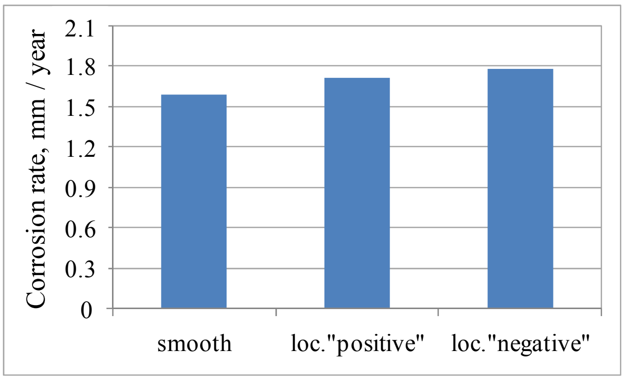

Figure 9. Corrosion rate of structured and smooth sheet metal

4. CONCLUSION

In this study, the corrosion resistance of structured and smooth sheet metals has been evaluated. For the purpose of examining steel specimens, the neutral salt spray test has been carried out. The test has shown the propagation of corrosion damage of structured sheet metals in salt environment with duration of exposure time.

From experimental measurements the weight loss rates have been calculated. Regression models with high precision have also been developed. The models describe the corrosion behaviour of structured and smooth sheet metals.

Besides, the dependence of thickness reduction as function of test duration has been illustrated. That allows estimating of corrosion behaviour for variable time periods.

The values of the corrosion rate have been used for the analysis and comparison of the corrosion properties for sheet metals. The results of this work clearly imply that structured and smooth sheet metals have different corrosion rates. This leads to the conclusion that corrosion resistance of sheet metals have been affected by the structuring process.

5. LIST OF SYMBOLS

corrosion area	A,	m²
weight loss	Δm,	g
steel density	ρ,	g/cm³
thickness reduction	Δs,	mm
exposure time	t,	h
weight loss rate	υ,	g/m²h
corrosion rate	ω,	mm/year

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