

RESPONSIBLE MANAGEMENT OF AGGREGATE WASTE TO IMPROVE THE PROPERTIES OF ANTI-CORROSION COATINGS

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Purpose: The aim of the study was to investigate the possibility of using engineering waste materials in the form of brick dust and volcanic tuff as corrosion inhibitors. The corrosion tests were carried out on the aluminium alloys against aggressive corrosive environments with acidic pH containing chlorine compounds.

Design/methodology/approach: The specimens for corrosion tests were cut from a sheet made of aluminium alloy EN AW-6060. In the first step the aluminium specimens was covered with a coating of clear alkyd varnish without any additives. In the next step used additives in the form of brick dust and volcanic tuff were used. The tests were carried out using a RADWAG AS 310.R2 laboratory analytical balance to obtain the weight loss results for the specimens tested.

Findings: Brick dust used in concentrations of 10% to 40% by weight cannot be considered as a material that allows achieving satisfactory results. This is due to the absorption of the corrosive medium by the brick dust. On the other hand, the volcanic tuff addition of 30% by weight creates conditions that slow down the corrosion process in the long term.

Research limitations/implications: Consideration should be given to preparing all types of structural components for corrosion protection by blunting sharp edges for better adhesion of corrosion protection coatings. Therefore, further work should focus on obtaining a coating with an adequate adhesion as well as checking the action of volcanic tuff as an inhibitor in other corrosive media.

Practical implications: The introduction of appropriately prepared volcanic tuff additives into protective coatings is expected to increase the effectiveness of the protection of the metal substrate against the corrosion process. It is therefore important to manage and monitor the factors that affect the coating and occur during the painting process.

Originality/value: In tests confirmed the good properties of volcanic tuff, which slows down corrosion processes and preserves the uniform corrosion of aluminium. The result obtained has the lowest mass loss values of all the specimens prepared in the experiment, which proves the validity of using the volcanic tuff additive.

Keywords: waste management, brick dust, volcanic tuff, corrosion inhibitor.

Category of the paper: Research paper.

1. Introduction

The economic development and the level and patterns of individual consumption are contributing to an increase in the amount of waste generated. The latest data show that 107,712,000 tonnes of waste (excluding municipal waste) were generated in Poland in 2021, from various branches of economic activity. The main sources of waste in 2021, as in previous years, were mining and the extractive industry (61.9% of total waste generated), industrial processing (22.0%) and electricity, gas, steam and hot water generation and supply (12.7%). As for the construction sector (3,504,000 tonnes of waste), it accounted for 3.3% of the waste generated. Of the total amount of waste generated in the period analysed, 48% of waste was recycled, 44% was disposed of by landfilling and 6% was disposed of by other means (GUS, 2022).

Therefore, proper waste management is an important link in the contemporary environmental policy of each member state of the European Union. In addition to introducing its own waste management regulations, Poland is also obliged to comply with and implement Community Regulations that ensure the even development of the natural economy (Żurawiecka, Kocia, 2019). Furthermore, waste management is an important component of sustainable development, according to which, the waste generated should have as little impact on the environment as possible. However, the main priority here will be waste prevention resulting from actions such as environmental education, waste prevention programmes, economic incentives for companies implementing recycling policies, and modelling of the waste management system based on quantitative, technical, economic and ecological criteria (Łagutko et al., 2018). On the other hand, a systemic understanding of our resources and waste systems reflects the challenges and compromises associated with the sustainable management of both resources and waste and their potential in a circular economy (Awasthi et al., 2021). And the latest research shows that the current way of managing waste needs to be significantly revised if closed-loop recycling is to be increased (Salmenperä et al., 2021).

Recently, environmental practices have resulted in a growing trend towards the use of recycled raw materials from recycled construction materials (Szafranko, Jaromińska, 2020, Huang et al., 2020, Bonoli et al., 2021, Oh et al., 2021). Waste from the construction industry is mainly concrete, asphalt, brick waste, ceramic waste, wood, metals, as well as plastics (Jura, 2017). The construction sector also accommodates the use of waste from other industries, e.g. waste from mines or steelworks (Wowkonowicz et al., 2018). On the other hand, in the case of extraction (mining) waste, the most popular method of managing it so far has been by dumping it in heaps or in mine workings. Increasingly, however, attempts are being made to process such materials, which not only promotes environmental protection, but also offers the possibility of recycling secondary raw materials (Jonczy et al., 2012).

An increasing number of companies and institutions see the need to use construction rubble as a substitute for natural aggregate in the production of concrete mixtures, which is due to economic and ecological reasons. By utilising construction rubble, the use of expensive natural aggregates is reduced, thereby also minimising the negative impact on the environment. A significant benefit is achieved when as much recycled aggregate as possible is used in the production of concrete. Among the fundamental reasons why recycling is becoming increasingly popular, the most important are the continuous increase in the amount of concrete waste and the steady increase in the use of concrete as a construction material (Sadowska-Buraczewska, 2014; Kalinowska-Wichrowska, 2018).

With the above in mind, new ways of using engineering waste materials, such as ground ceramic waste in the form of brick dust and volcanic tuff, which is treated as waste in quarries, are increasingly being sought. These materials are classified as lightweight aggregates suitable for concretes and mortars. The current standard for lightweight aggregates PN-EN 13055:2016-07 divides the materials into four groups, i.e. natural, artificial, waste and recycled, where volcanic tuff is classified as a natural aggregate and brick dust being crushed ceramic rubble is classified as a recycled aggregate (Fig. 1). Another standard, EN 206+A2:2021-08, defines aggregate as a natural, artificial, recycled or reclaimed granular component suitable for use in concrete.

The first aggregate mentioned, i.e. brick dust, is a material derived from the crushing of bricks and has been successfully used for tennis court and running track surfaces, or as an ingredient in mixtures and grits for asphalt and concrete (Pluska, 2009; [https://erobocze.pl/...](https://erobocze.pl/), 2023). It is also widely used in the construction sector as an additive for mortar and concrete (Wild, 1996; Szwabowski et al., 1999; Dündar et al., 2020; Xue et al., 2021). In addition, brick dust has been used as a raw material for the preparation of geopolymer mixtures (Fořt et al., 2017) as well as a dusty material to enhance the sedimentation properties of activated sludge (Masłoń, 2015). Brick dust can also be a waste material from the production of hollow bricks (Fořt et al., 2017).

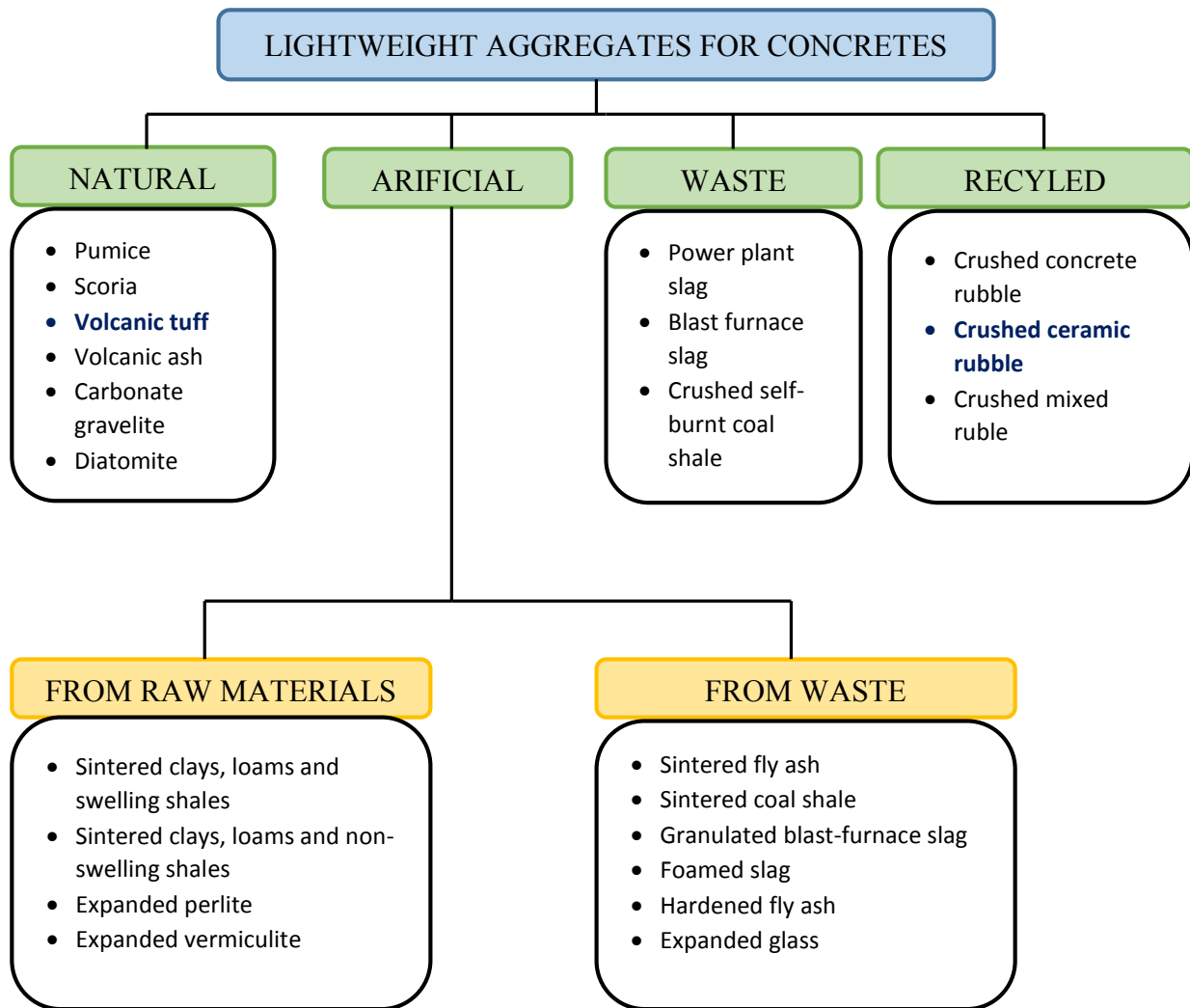


Figure 1. Classification of lightweight aggregates for concretes.

Source: Domagała, 2014.

As for the other waste material, i.e. volcanic tuff, it is a porous rock belonging to the clastic rocks and consists of pyroclastic material, often with the admixture of other clastic material, cemented with e.g. a silica or clay binder (<http://swiat...>, 2023). A characteristic feature of tuff is its high porosity which is associated with low specific gravity. Tuffs also include clay minerals and zeolites (Mikuła, Łach, 2012). The available literature contains many applications of volcanic tuffs, such as e.g. a raw material for the production of lightweight structural aggregates in the production of lightweight concrete, or for the production of rigid polyurethane-polyisocyanurate foams (Paciorek-Sadowska et al., 2016), a durable component for the production of cements, a mineral for the production of highly durable ceramic pigments and dyes, or a material for the production of geopolymer binders (Mikuła, Łach, 2012, 2014), and an attractive material for cosmetic preparations, such as e.g. scrubs (Mikuła, Łach, 2012). In addition, volcanic tuffs are an important tool in solving numerous environmental problems through their potential to remove ammonia, heavy metals (mainly lead) from municipal wastewater, and caesium and strontium from water from nuclear power plants (Grela et al.,

2013). It should be noted that a significant problem often encountered with the use of such materials is the variability of the mineral composition and characteristics depending on their place of occurrence. This affects the quality characteristics of cementitious materials in which volcanic tuff is used as a modifier. On the one hand, these materials may have a favourable chemical and mineralogical composition, but on the other hand, they may exhibit some not so good properties in the form of high water demand, and thus consistency of the concrete mixture (Shannag, Yeginobali, 1995; Pekmezci, Akyüz, 2004; Yılmaz, Ediz, 2008). It should also be emphasised that volcanic tuff particles can be successfully used as an additive for paints and varnishes due to their highly developed surface and sorption properties as well as abrasion resistance (Mikuła, Łach, 2012).

The aim of this paper is to investigate the possibility of using engineering waste materials, such as brick dust and volcanic tuff for corrosion protection of components made of aluminium alloys that come in contact with an aggressive acidic environment containing chlorine compounds. It should be emphasised in this context that it is a common belief that components made of aluminium do not corrode. The reason for this is usually the formation of an aluminium oxide film (Al_2O_3) which effectively protects the metal from the damaging effects of aqueous corrosive environments. This is evident from the potential-pH correlation for the Al-H₂O pair shown (Fig. 2).

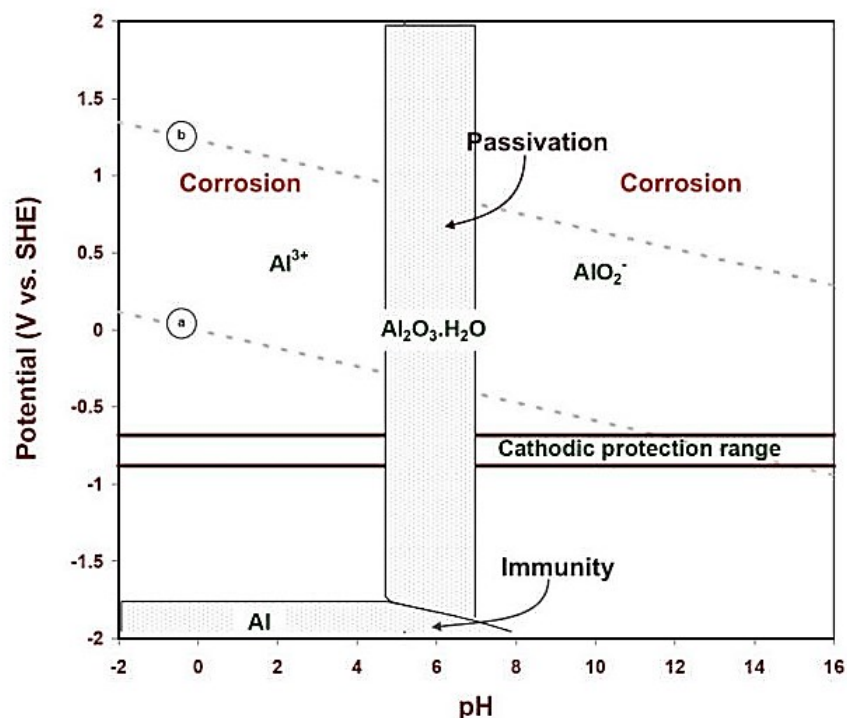


Figure 2. Potential-pH diagram of aluminium at 25°C.

Source: www.corrosion-doctors.org..., 2023.

From Figure 2, it is possible to determine the theoretical conditions under which aluminium should corrode or passivate due to the formation of gibbsite (hydrargyllite). This shows that for aqueous solutions with a pH in the range of 4.0 to 7.0, aluminium dissolution is not possible.

Thus, any cracks in the oxide coating, whether mechanical or chemical, will immediately seal themselves up. However, under conditions other than those indicated above, the aforementioned layer does not provide adequate protection (Shreir, 1976).

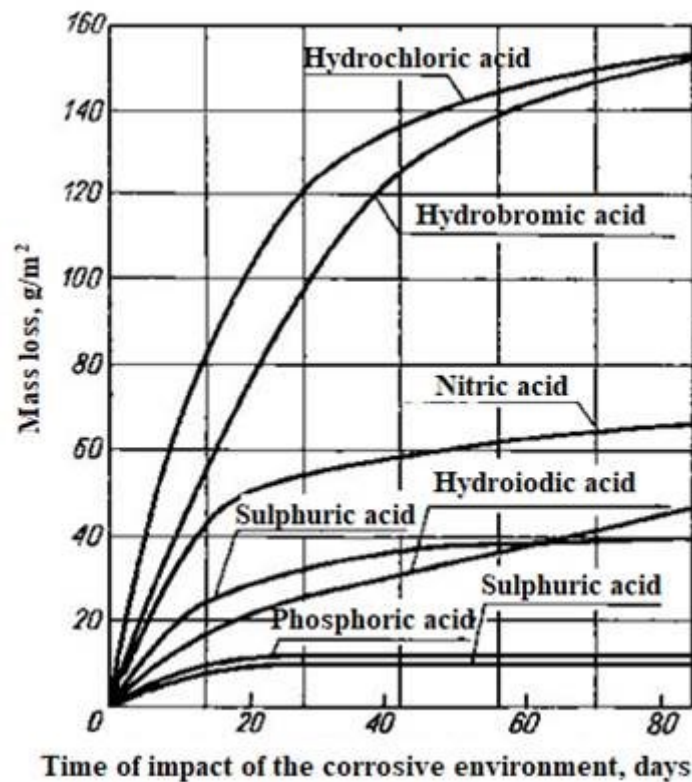


Figure 3. Diluted (0.1n) solutions of inorganic acids on commercial grade aluminium at 25°C.

Source: own work based on Shreir, 1976.

Particular attention should be paid to the corrosive effect of compounds in the form of inorganic acids (Fig. 3). The solution with the strongest impact on weight loss is hydrogen chloride (HCl). Chlorine is one of the main agents that act aggressively on components made of aluminium alloys. In practice, however, it is possible to distinguish a deliberate use of chlorine compounds in the food industry for preliminary digestion of fruit peels with hydrochloric acid, which peels are then subjected to a preservation process while it is of course necessary to make sure that suitable tools and containers are used to carry out this process so that the corrosion products are not processed together with the food. During winter periods, it is advisable to use an aqueous solution of sodium chloride (NaCl) with a concentration of 97% (Czarna, Kołodziejczyk, 2012) to remove hard-packed snow. A disadvantage is the corrosive effect of this compound on both motor vehicles (e.g. rims, heat shields, suspension components and bodywork) and urban infrastructure (e.g. pipelines, water pipes and other structural components) (Białobrzeski et al., 2002). Another example is the shipbuilding industry where it can be noticed that adequate protection against the effects of salty seawater is crucial for the service life of ships. In addition, the use of aluminium alloys for ship structures makes it possible, among other things, to reduce the final weight of the vessel by more than half, which

translates into operational capabilities such as increased cruising speed, manoeuvrability, stability conditions, etc. (Cudny, Puchaczewski, 1996; Jurczak, 2010).

It is also worth noting the high amount of chlorine in swimming pool water – provision should be made for the use of appropriate fittings so that sudden failures do not occur during use. Another industry where there is contact with an aggressive environment containing chlorine compounds is the mining industry. The method used here is that of borehole acidification. The reaction of hydrogen chloride with the rock intensifies and leads to the development of pores and fractures as well as the dissolution of the rock body (Fabia et al., 2011). During subsequent mining processes, parts of the machinery and equipment are exposed to the residues of the compounds used.

2. Materials and methods

Aluminium alloy EN AW-6060 was chosen for the experimental study. It is characterised by medium mechanical strength and impact strength, and good corrosion resistance. It is suitable for anodising and is amenable to polishing. It has average fatigue strength and is machinable (EN 573-3+A1:2022-11). The chemical composition of the material is shown in Table 1.

Table 1.
EN AW-6060 chemical composition

	Fe [%]	Si [%]	Zn [%]	Ti [%]	Mg [%]	Mn [%]	Cu [%]	Cr [%]	Other [%]	Al [%]
min.	0.10	0.30	-	-	0.35	-	-	-	-	-
max.	0.30	0.60	0.15	0.10	0.60	0.1	0.1	0.05	0.15	rest

Sources: PN-EN 573-3+A1:2022-11.

The material tested is characterised by an increased content of magnesium (Mg) and silicon (Si). According to A. Domony, the addition of magnesium increases the strength properties and corrosion resistance. On the other hand, the negative effect is a decrease in electrical conductivity. Furthermore, the addition of silicon as an alloying element increases the strength properties while decreasing the electrical conductivity. Also, with regard to its occurrence in the structural components, it does not affect the corrosion properties in solid solution, but it compromises corrosion resistance in a mixture (PN-EN 573-3+A1:2022-11).

Due to the silicon content in the chemical composition, a microstructure of the aluminium alloy indicated above was produced in the as-delivered condition to verify this information (Fig. 4). A sample of the material was embedded in a plastic and then subjected to grinding using abrasive grinding papers with decreasing grit coarseness. The surface was then polished until the scratches disappeared. The metallographic specimens were observed in the condition as-etched by 0.5% HF solution. The image was taken using a JEOL JSM 5510 LV Scanning Electron Microscope.

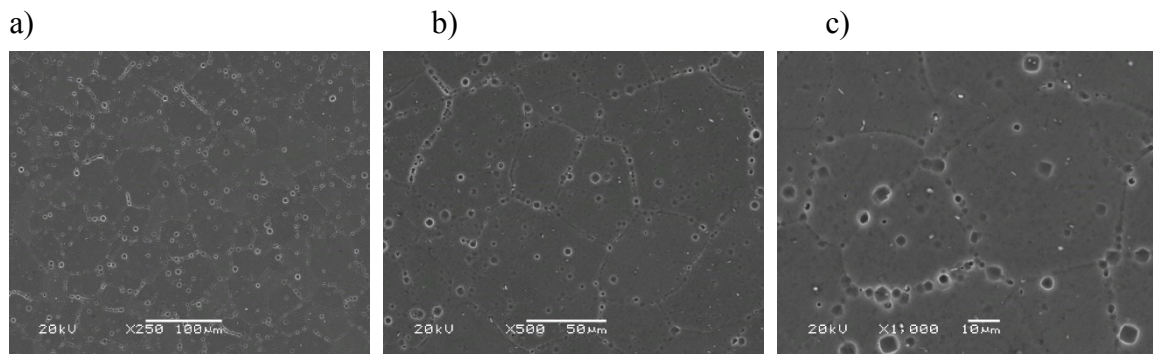


Figure 4. Microstructure of aluminium alloy AW-6060 (0.5% HF) as delivered – magnification: (a) 250x, (b) 500x, (c) 1000x.

Source: own work.

From the images obtained it appears that alloy 6060 has a single-phase structure with numerous precipitates (probably Mg_2Si) at the grain boundaries indicating that it is in a precipitation-hardened condition. Thus, the information regarding the absence of a structural component in the mixture containing silicon is confirmed. This proves the absence of a negative effect of silicon on the corrosion properties.

The specimens for corrosion testing were cut from a sheet made of aluminium alloy EN AW-6060. The test specimens were prepared in accordance with EN/ISO 7384:2001 – the specimen geometry is presented in Fig. 5. The surface of the material in the as-delivered condition is shown in Fig. 6.

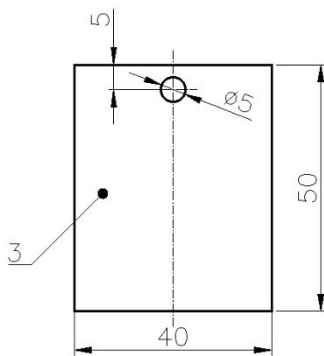


Figure 5. Dimensions of specimens for corrosion testing.

Source: PN-EN/ISO 7384:2001.



Figure 6. Surface of a raw aluminium specimen.

Source: own work.

Before proceeding, the specimens were prepared by roughening the surface with P120-grit sand paper and degreased to remove contaminants. Anti-corrosion coatings were applied onto the thus prepared surface. The primary protection was clear alkyd varnish for use on metals. The aluminium specimen was covered with a coating without any additives in order to identify the delay or acceleration of corrosion processes relative to the varnish with weight additives of the waste materials selected for testing. The waste material additives are either brick dust or volcanic tuff. The former is brick dust for which four different additives by weight were used

(+10%, +20%, +30% and +40%). The wide range of use of the additive is related to the lack of information on the use of the indicated waste material in this form as an additive for varnishes or other products. On the other hand, the use of volcanic tuff (aluminosilicates) is based on a literature analysis and the achievements of Prof. J. Mięka's research team (Mięka, Łach, 2012; Hebdowska-Krupa, Mięka, 2006, 2007; Hebdowska-Krupa et al., 2016). This material has been shown to alter the nature of steel corrosion (Hebdowska-Krupa, Mięka, 2007) and to slow down corrosion processes (Hebdowska-Krupa et al., 2016) thus being a corrosion inhibitor. The use of additives in the form of aluminosilicates for artificial materials can take values ranging from 10% to 30% (Mięka, Łach, 2012). Therefore, the authors decided to apply in their investigation the indicated maximum limit value of the tuff additive to the alkyd varnish. For comparison purposes, an additional zinc coating was applied by spraying onto an aluminium specimen (double layer).

Following the application of the first layer, each specimen was subjected to a drying process at room temperature before the second layer was applied. The double application of the anti-corrosion coating is intended to thoroughly cover the surface of the protected metal in case of inaccuracies and discontinuities that may occur when only one layer is applied. The discontinuity of the anti-corrosion coating through the resulting defects allows the corrosion medium to contact the protected metal and initiate one of the types of corrosion, e.g.: sub-surface corrosion. A list of all types of specimens used for testing is shown in Table 2.

Table 2.
Specimens used for corrosion testing in a 2% HCl solution

(1) AW-6060	(2) AW-6060 + alkyd varnish	(3) AW-6060 + alkyd varnish +10% dust	(4) AW-6060 + alkyd varnish +20% dust	(5) AW-6060 + alkyd varnish +30% dust	(6) AW-6060 + alkyd varnish +40% dust	(7) AW-6060 + alkyd varnish +30% tuff	(8) AW-6060 + zinc coating
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Source: own work.

3. Analysis of the results

An aqueous solution environment containing 2% hydrochloric acid (HCl) was used to carry out the accelerated corrosion tests. The relatively low percentage concentration of the solution was chosen intentionally so that the corrosion process should take place relatively slowly. Rapid chemical reactions are associated with the release of a certain amount of heat and, consequently, with an increase in the temperature of the corrosive medium. This causes disturbances related to the rate of the corrosion process and inadequate practical conditions,

e.g. the corrosion of certain automotive components that are repeatedly exposed to chlorine, especially during the winter months.

The tests were carried out using a RADWAG AS 310.R2 laboratory analytical balance to obtain the weight loss results for the specimens tested. Each specimen was subjected to a drying process at room temperature for a period of 3-6 hours and then weighed. The results of the tests are presented in Tables 3-10.

Table 3.

Examples of corrosion test data for AW-6060 in a 2% HCl solution

Specimen	Initial weight of the specimen [g]	Exposure time [h]	Weight measurement [g]	Weight loss [g]	Corrosion rate [g/h]
(1) AW-6060	15.9345	29	15.697	0.2375	0.00819
		60	15.5273	0.4072	0.00547
		202	14.6364	1.2981	0.00627
		322	14.1974	1.7371	0.00366
		513	13.4357	2.4988	0.00399
		630	13.0453	2.8892	0.00334

Source: own work.

Table 4.

Examples of corrosion test data for AW-6060 with added alkyd varnish in a 2% HCl solution

Specimen	Initial weight of the specimen [g]	Exposure time [h]	Weight measurement [g]	Weight loss [g]	Corrosion rate [g/h]
(2) AW-6060 + 1 alkyd varnish	16.4472	29	16.439	0.0082	0.00028
		60	16.432	0.0152	0.00023
		202	16.1054	0.3418	0.00230
		322	15.058	1.3892	0.00873
		513	13.9834	2.4638	0.00563
		630	13.4646	2.9826	0.00443

Source: own work.

Table 5.

Examples of corrosion test data for AW-6060+alkyd varnish+10% brick dust in a 2% HCl solution

Specimen	Initial weight of the specimen [g]	Exposure time [h]	Weight measurement [g]	Weight loss [g]	Corrosion rate [g/h]
(3) AW-6060 + alkyd varnish + 10% dust	16.609	29	16.6014	0.0076	0.00026
		60	16.5993	0.0097	0.00007
		202	16.6141	-0.0051	-0.00010
		322	16.2307	0.3783	0.00320
		513	14.307	2.302	0.01007
		630	13.5656	3.0434	0.00634

Source: own work.

Table 6.

Examples of corrosion test data for AW-6060+alkyd varnish+20% brick dust in a 2% HCl solution

Specimen	Initial weight of the specimen [g]	Exposure time [h]	Weight measurement [g]	Weight loss [g]	Corrosion rate [g/h]
(4) AW-6060 + alkyd varnish + 20% dust	16.7335	29	16.7251	0.0084	0.00029
		60	16.7214	0.0121	0.00020
		202	16.5483	0.1852	0.00092
		322	15.0826	1.6509	0.00513
		513	14.0462	2.6873	0.00524
		630	13.4588	3.2747	0.00520

Source: own work.

Table 7.

Examples of corrosion test data for AW-6060+alkyd varnish+30% brick dust in a 2% HCl solution

Specimen	Initial weight of the specimen [g]	Exposure time [h]	Weight measurement [g]	Weight loss [g]	Corrosion rate [g/h]
(5) AW-6060 + alkyd varnish + 30% dust	16.6328	29	16.6244	0.0084	0.00029
		60	16.6237	0.0091	0.00015
		202	16.5943	0.0385	0.00019
		322	16.2146	0.4182	0.00130
		513	14.3806	2.2522	0.00439
		630	13.3861	3.2467	0.00515

Source: own work.

Table 8.

Examples of corrosion test data for AW-6060+alkyd varnish+40% brick dust in a 2% HCl solution

Specimen	Initial weight of the specimen [g]	Exposure time [h]	Weight measurement [g]	Weight loss [g]	Corrosion rate [g/h]
(6) AW-6060 + alkyd varnish + 40% dust	16.867	29	16.8605	0.0065	0.00022
		60	16.8628	0.0042	0.00007
		202	16.9792	-0.1122	-0.00056
		322	16.6784	0.1886	0.00059
		513	14.4452	2.4218	0.00472
		630	13.656	3.211	0.00510

Source: own work.

Table 9.

Examples of corrosion test data for AW-6060+alkyd varnish+30% volcanic tuff in a 2% HCl solution

Specimen	Initial weight of the specimen [g]	Exposure time [h]	Weight measurement [g]	Weight loss [g]	Corrosion rate [g/h]
(7) AW-6060 + alkyd varnish + 30% tuff	16.276	60	15.914	0.362	0.00603
		202	16.155	0.121	0.00060
		322	15.677	0.599	0.00186
		513	15.34	0.936	0.00182
		630	15.104	1.172	0.00186

Source: own work.

Table 10.

Examples of corrosion test data for AW-6060+zinc coating in a 2% HCl solution

Specimen	Initial weight of the specimen [g]	Exposure time [h]	Weight measurement [g]	Weight loss [g]	Corrosion rate [g/h]
(8) AW-6060 + zinc coating	16.146	60	15.88	0.266	0.00443
		202	15.969	0.177	0.00088
		322	15.372	0.774	0.00240
		513	14.73	1.416	0.00276
		630	14.303	1.843	0.00293

Source: own work.

A summary of the test results showing percentage of weight loss as a function of time is shown in Figure 7.

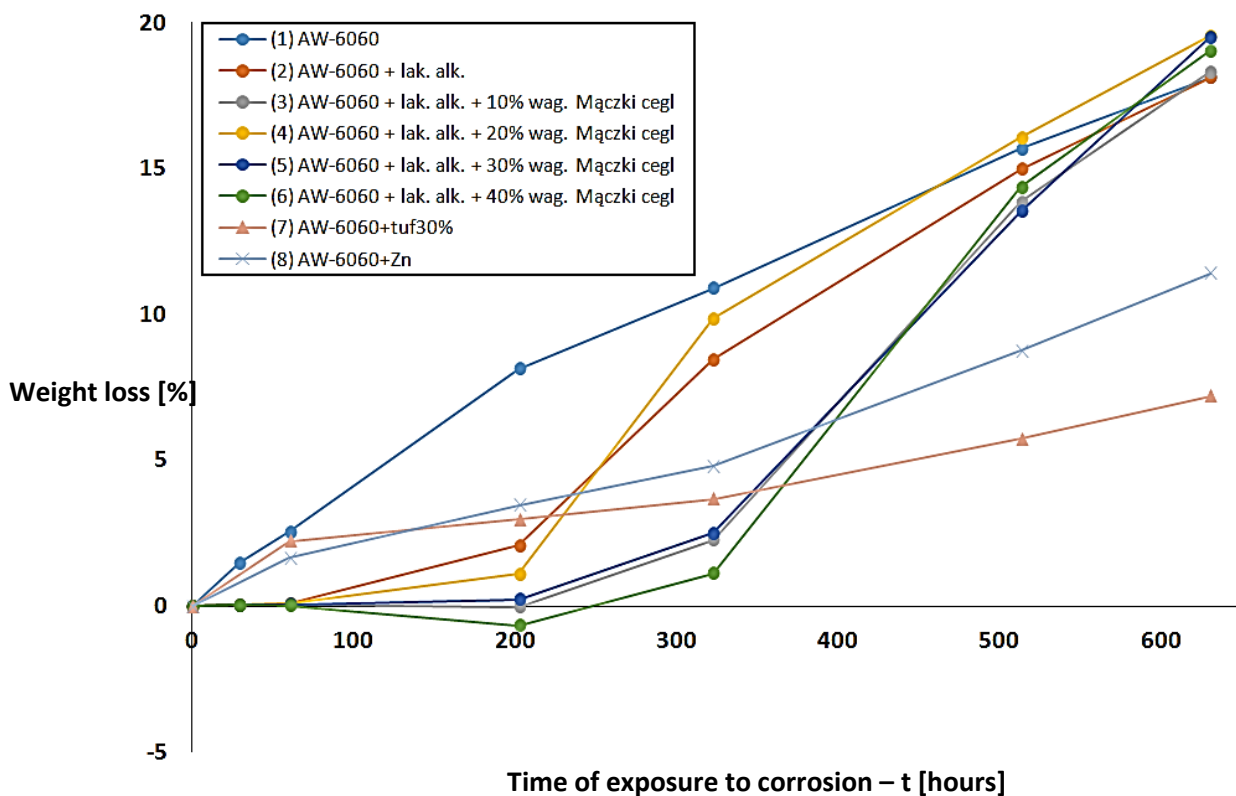


Figure 7. Percentage of weight loss for aluminium alloy AW-6060 in different configurations of corrosion protection layers as a function of time.

Source: own work.

During the study, photographs were taken of the specimens during the breaks when the specimens were weighed. A Levenhuk DTX 90 digital microscope was used to capture the changes in photographs. Figures 8-13 show a selection of the more interesting cases. The magnification of the images presented is 60x.



Figure 8. Specimen AW-6060 without corrosion protection coating – 630 hours.

Source: own work.



Figure 9. Specimen AW-6060 with alkyd varnish – 630 hours.

Source: own work.



Figure 10. Specimen AW-6060 with alkyd varnish +10% brick dust – 630 hours.

Source: own work.

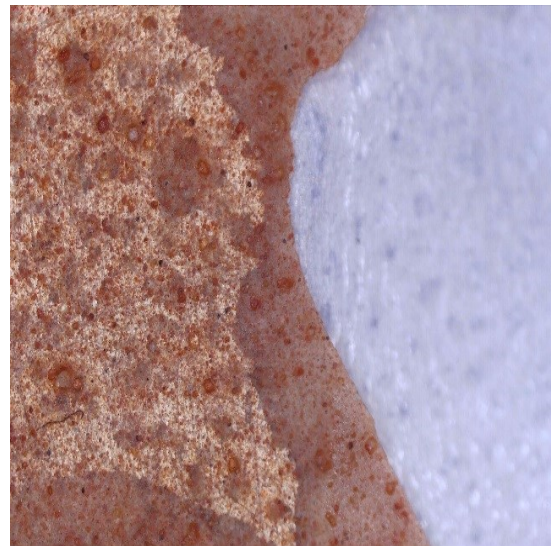


Figure 11. Specimen AW-6060 with alkyd varnish +20% brick dust – 630 hours.

Source: own work.



Figure 12. Specimen AW-6060 with alkyd varnish +40% brick dust – 630 hours.

Source: own work.



Figure 13. Specimen AW-6060 with alkyd varnish +30% volcanic tuff – 630 hours.

Source: own work.

The baseline specimen AW-6060 without a coating corroded in a manner close to rectilinear throughout the test range. Corrosion occurs in a uniform manner revealing the rolling direction (Fig. 8). This is the safest of all the possible types of corrosion due to its stability and predictability. Throughout the test period, hydrogen bubbles were present on the surface of the specimen indicating a process of progressive corrosion. This process took place without violent reactions. This therefore makes it possible to realistically estimate the service life of components exposed to a corrosive environment before they are replaced during maintenance. This type of assumption enables designing components with an additional allowance for excess material. The allowance is related to ensuring a safe cross-section over the entire range of use for the particular type and degree of load.

Alkyd varnish used as a varnish base in the initial phase of the process protects the metal from the corrosive environment. After approx. 200 hours this varnish peels off the surface at some spots where the target corrosion of the metal begins. Figure 9 shows a sample after 630 hours of testing. There are three zones visible on it. The first one is light grey with a well-adhered coating, the second one is in the form of a thin grey stripe indicating a lack of cohesion of the coating with the metal, and the third one is where the corrosion of the metal occurs. The weight loss relative to the base sample evens out after 630 hours of testing. To a large extent this is related to the peeling off of the coating which represents a sudden drop in the weight of the specimen. It can be assumed that the losses for both specimens will continue to be at a similar level.

Brick flour applied in weight concentrations of between 10% and 40% cannot be considered as a material that enables achieving satisfactory results (Fig. 10-12). This is related to the absorption of the corrosive medium by the brick dust. The absorption phenomenon allows the corrosive medium to penetrate and come into contact with the protected metal. The degree of

permeation depends on the percentage addition by weight – the higher the addition, the greater the absorption. This manifests itself as a swelling of the coating – without breaking the continuity of the coating. This is associated with an increase in weight – especially for the specimen with 40% addition of brick dust by weight (Fig. 7 – specimen (6) for test time $t = 202$ h). However, the process of corrosion does not occur instantaneously due to the preserved continuity of the coating. This significantly limits the exchange of the corrosive agent. It can be concluded that the flexibility of the coating is preserved. The acceleration of the corrosion process occurs due to a local break in the continuity of the coating at the sharp edges of the component (side edges). This results in a violent reaction in the form of the release of a significant amount of hydrogen bubbles over a relatively small area of the aluminium component. This causes dissolution of the metal and the formation of aluminium chlorides (AlCl_3). The process taking place is very unfavourable due to the change in the nature of the corrosion in relation to the baseline specimen (1) AW-6060 from uniform corrosion into uneven corrosion. If this is the case, estimation of the rate of the corrosion process and the effects that will arise becomes problematic. As a result of the observations, it should be noted that the coating (mainly for the 30% and 40% additive) does not degrade in the corrosive environment. For the purpose of photographing the metal surface, the protective coating was removed mechanically (Fig. 12). However, it retains its integrity by forming a permanent shell separated from the protected metal being an effect of subsurface corrosion. These coating discontinuities can be identified by the noticeable release of a significant quantity of hydrogen at the break points.

The volcanic tuff additive, 30% by weight, creates conditions that slow down the process of corrosion in the long term. In the first phase, small parts of the coating peel off (Fig. 13), which accounts for the initial increase in the percentage of weight loss. It can be concluded that although the coating itself does not perform its function sufficiently well, the volcanic tuff additive itself is a corrosion inhibitor. This effect was achieved and observed in the already mentioned studies conducted by Hebdowska M. & Mikula J. for steel components. Our own investigation confirms the very good properties of volcanic tuff as it slows down corrosion processes and preserves the uniform corrosion of aluminium. The result obtained has the lowest weight loss values of all the specimens.

In the course of observing the specimens, it was noted that where the hole was made and its sharp edges were blunted, the degree of adhesion of the coatings was much higher than in the case of the sharp outer edges of the test pieces (Fig. 14).



Figure 14. Round hole in specimen AW-6060 with alkyd varnish +40% brick dust – 630 hours.

Source: own work.

Due to structural considerations, a suitable method for preparing the components and blunting the sharp edges must be envisaged. It seems that the most sensible solution here is by rounding off sharp geometric transitions as this will increase the probability of maintaining the continuity of the corrosion protection coating over a wider range of time.

4. Summary

The revision of the so-called Waste Framework Directive (Directive (EU), 2018) introduces a new approach to waste management, moving away from thinking of waste in terms of an unwanted burden on the environment towards treating it as a valuable resource. This Directive primarily focuses on waste prevention and sets new targets that will help the EU achieve its overarching goal of becoming a recycling society.

The current approach to managing waste in the form of aggregates is mainly based on the construction sector. It should also be noted that construction and demolition waste is one of the most burdensome types of waste generated in the EU. It accounts for approx. 25-30% of all waste generated and consist of a wide range of materials, many of which can be recycled.

The investigation carried out by the authors of this paper was aimed at assessing the possibility of using engineering waste materials for corrosion protection of aluminium alloy components in contact with an aggressive corrosive environment with an acidic pH containing chlorine compounds. The varnish additives used in the tests were brick dust and volcanic tuff. Due to the lack of information regarding the possibility of using brick dust, different percentages of additives were used, ranging from 10% to 40% by weight. For the varnish-coated samples with volcanic tuff, the addition was 30% – this value is justified by research findings (Hebdowska-Krupa, Mikuła, 2006, 2007; Mikuła, Łach, 2012; Hebdowska-Krupa, M., Łach, M., Mikuła, 2016). The above studies show that the use of this additive does not adversely affect the properties of polymer products and it can be used successfully.

Based on the testing carried out in the form of weight loss measurements as well as observations of the processes taking place, the following conclusions can be drawn:

- In the context of the use of waste materials in the form of brick dust, the absorption (soaking) of the corrosive agent is a disqualifying factor.
- The addition of volcanic tuff to alkyd varnish has provided promising test results for components made of aluminium alloy.
- The preparation of all kinds of structural components for corrosion protection should include the blunting of sharp edges for better adhesion of corrosion protection coatings.

In accordance with the above, further work on volcanic tuff should focus on obtaining a coating with an adequate degree of adhesion as well as checking the action of tuff as an inhibitor in other corrosive media. In the case of brick dust, a desirable line of research would be to test the possibility of using it as a corrosion inhibitor in an atmosphere of different gases.

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