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## Corrosion of Metal in Wood Products

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**ABSTRACT:** A description is given of the source of metal corrosion products that cause wood deterioration around corroding metal in wet wood. Corrosion of isolated steel fasteners in wood and the formation of acid conditions around the corroding steel is explained in terms of "crevice corrosion." The source of acid and alkaline conditions around corroding metals undergoing galvanic corrosion and the source of alkaline conditions around cathodically protected metal also are explained.

Results of a 3-year corrosion test of eleven wood fastener materials in wood treated with copper-containing waterborne salt preservatives indicate that, when long service life is required under wet conditions, fastener materials that are cathodic with respect to copper should be chosen. The literature indicates that metals in contact with fire retardant-treated lumber and cellulose insulation under high moisture conditions also may be subject to corrosion.

**KEY WORDS:** metal corrosion, corrosion damage, wood preservatives, wood products, cellulose, insulation, galvanic corrosion, fire resistant coatings, cathodic protection, building materials, durability

It is commonly observed that wood weakens around corroding metal such as nails, spikes, screws, bolts, and plates in house siding, rail ties, boat docks, highway trailer beds, and wooden vessels. Damp wood not only causes metals to corrode because wood is slightly acid, but when a metal fastener is embedded in wet wood, conditions are created that can accelerate the corrosion of the metal. The corrosion products often result in slow deterioration of the wood surrounding the metal. Corrosion of the fastener combined with deterioration of the wood causes loss of strength of the joint and weakening of the structural integrity of the assembly. The literature on wood-metal corrosion has been reviewed carefully by Graham et al [1].<sup>2</sup>

The causes and cures of wood weakened around corroding metal have been

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<sup>2</sup>The italic numbers in brackets refer to the list of references appended to this paper.

the subject of several research publications. Marian and Wissing [2-4] have reported on the chemical analysis and the physical properties of wood in contact with corroding steel. Farber [5] and Savard and Caumartin [6] have shown the iron content of rail ties is high under tie plates and near rail spikes; they indicate the loss of strength is due to the corroding steel. Pinion [7] has reported the corrosion of fasteners in wooden vessels to be due to oxygen concentration gradients between the exposed end of a fastener and the portion embedded in the wet wood.

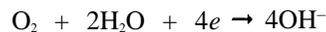
This report presents information on the theory of metal corrosion as it relates to the corrosion products that initiate deterioration in the damp wood that is in contact with the corroding metal fasteners [8]. In addition, new data are presented on the corrosion of eleven fastener materials in waterborne salt preservative-treated wood together with a brief discussion of the corrosion of metals in contact with fire-retardant-treated wood products.

## Corrosion of Metal in Damp Wood

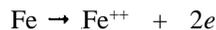
### *Isolated Metal Fastener*

For a single or an isolated metal fastener in damp wood, its corrosion can be explained in terms of crevice corrosion theory. This type of corrosion occurs in crevices such as a long tack welded, riveted, and bolted joints of tanks and pipes. The following explanation for the corrosion of a steel nail in damp wood is similar to that for crevice corrosion of a riveted section of steel in aerated seawater given by Fontana and Greene [9]. Figure 1 shows the conditions that are possible after corrosion has progressed.

Pinion [7] noted that the exposed end of a steel fastener in damp wood quickly shows evidence of hydroxyl ion (OH<sup>-</sup>) formation. This indicates that the exposed head of a nail, or of some other metal fastener, becomes the cathode and the shank becomes the anode of a galvanic corrosion cell. The chemical reaction at the cathode can be written



The reaction at the anode for a steel nail can be written as follows:



Ferrous ions (Fe<sup>++</sup>) liberated at the anode are oxidized readily to form ferric ions (Fe<sup>+++</sup>) and can react to form either black iron tannate dyes or rust. Iron ions are active catalysts and they promote chemical reactions that cause a loss of strength in cellulose and wood [2].

Damp wood can be considered as an electrolyte or slightly acidic solution. Soluble chlorides present in the bulk solution can migrate to a steel nail and

result in accelerated corrosion of the nail and a weakening of the wood. As the reactions at the anode and the cathode proceed, chloride ions ( $\text{Cl}^-$ ) and hydroxyl ions ( $\text{OH}^-$ ) migrate from the bulk solution into the crevice between the nail and the wood (Fig. 1). Iron ions formed at the anode in the crevice react with hydroxyl ions in both the crevice and bulk solution to form insoluble iron hydroxides. The formation of insoluble iron hydroxide in the crevice leaves the solution acidic because of the relative decrease in concentration of hydroxyl ions compared to that of the hydrogen ions ( $\text{H}^+$ ). The solution within the crevice thus becomes acid due to high concentration of ( $\text{H}^+$ ).

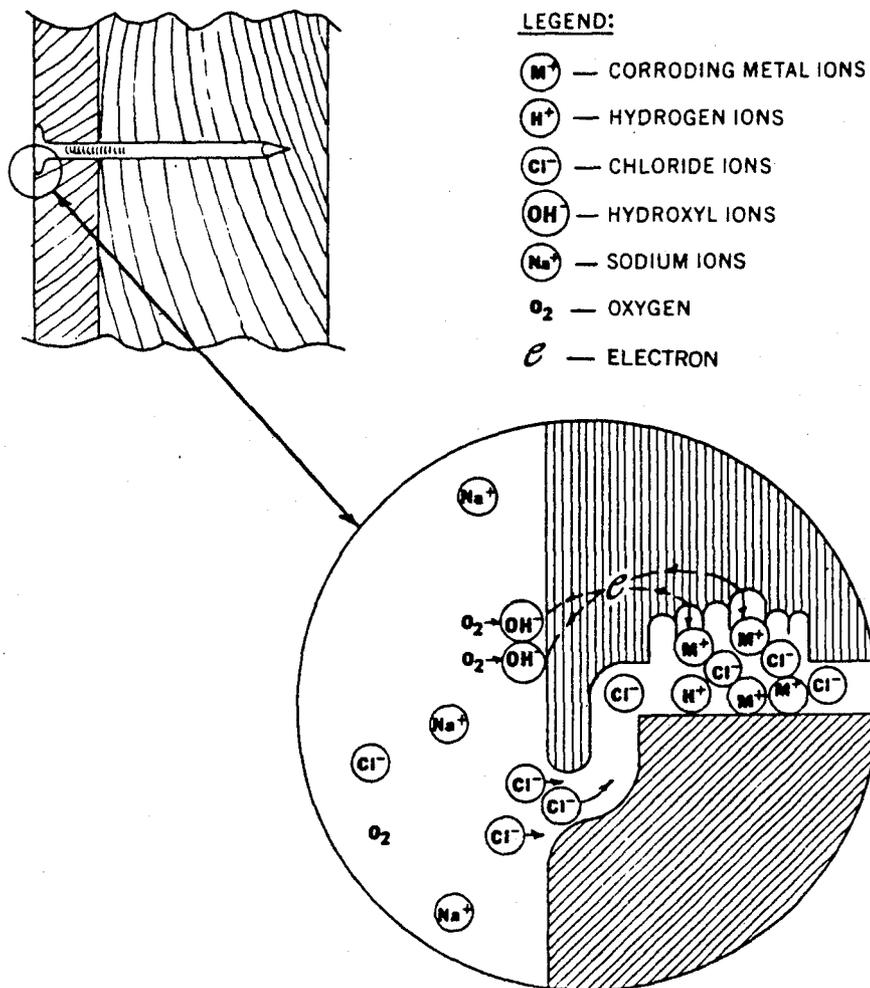


FIG. 1—Schematic of conditions possible after crevice corrosion has progressed.

These conditions accelerate the corrosion of the metal and the formation of additional acid. Fontana and Greene [9] report that the fluid within crevices exposed to neutral dilute sodium chloride solution has been observed to contain 3 to 10 times as much chloride as the bulk solution and to possess a pH of 2 to 3. The acid conditions developed along the nail shank can hydrolyze the cellulose and weaken the wood.

The hydroxyl ions formed at the external cathode usually will not affect the wood if exposure to free water will wash them away before any appreciable concentration of hydroxide is reached.

Copper and its alloys undergo a different form of crevice corrosion than do ferrous or aluminum-based metals when immersed in flowing water [10]. Copper enters the solution at both the exposed surface and the surface within the crevice. At the exposed surface, the copper ions are washed away by the water. This results in a higher concentration of copper ions in the crevice relative to the concentration at the exposed end, thus establishing a differential metal-ion corrosion cell. The higher concentration of copper ions in the crevice causes the copper metal in the crevice to become cathodic. The exposed copper then becomes the anode. The predominant cathodic reaction is the reduction of oxygen to form hydroxyl ions (alkaline conditions) which, in time, will cause deterioration of the adjacent wood. This could explain the condition of weakened wood found around isolated silicon bronze bolts in minesweepers [11].

Crevice corrosion usually requires an incubation period to develop, but once started it proceeds at an ever-increasing rate.

Stress corrosion cracking of tempered carbon steel nails (quenched and tempered AISI 1035 carbon steel) has been observed when used in Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and western larch (*Larix-occidentalis* Nutt.) exposed to a warm humid environment over log heating chambers in veneer mills [12]. A threshold level of susceptibility to stress corrosion cracking was found after laboratory tests in Douglas-fir extract (pH 4.3) and 0.1 N acetic acid (pH 2.1). As a result nails with a hardness range of RHC 32 to 39, and an ultimate tensile strength range of 1000 to 1210 MPa, will be required for nails in a revised CSA standard 086. A hot dip galvanized finish also will be required to resist occasional wetting.

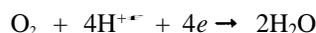
### ***Dissimilar Metals***

Dissimilar metals in contact with one another in a corrosive environment form a galvanic cell that results in accelerated corrosion of the less corrosion-resistant metal and very little attack of the more resistant metal. A galvanic series of metals and metal alloys in sea water is helpful in predicting possible galvanic relationships. Thus, with dissimilar metals in electrical contact, the more noble metal becomes the cathode and the less noble one becomes the anode. Corrosion occurs at the anode. If the metal is embedded in wood, it is

possible that acid could accumulate adjacent to the anode. Also, if the anode is iron, then the ferrous ions can initiate degradation of wood. At the cathode, the chemical reaction depends on the conditions. In neutral solutions, the reaction is



Under acid conditions, the reaction is:



Since damp or moist wood is acid with a pH range of 4 to 6, the second equation probably best describes the initial cathode reaction. This reaction consumes  $\text{H}^+$  ions and, after  $\text{H}^+$  ions are depleted, the reaction can be described by the first equation. This explains the frequent finding of alkaline conditions around a metal cathode in wood. After a number of years, the accumulation of alkali can weaken the wood seriously.

#### ***Cathodically Protected Metal***

The formation of alkaline conditions at the cathode and the resulting wood degradation describe the phenomenon that occurs in wooden vessels around embedded metal that is being protected cathodically against sea water corrosion. It is common to protect the immersed metal on ships from corroding by cathodic protection. This is accomplished by attaching zinc or magnesium anodes to the vessel, and connecting these either directly or by a conducting wire to the immersed metal. The anode is a sacrificial metal, and it corrodes preferentially to the immersed metal. For a wooden vessel, the metal to be protected is purposely made the cathode. However, it is often overlooked that the alkaline reaction product at the cathode, in time, can result in loss of strength of the adjacent wood. The end result is that, although the metal does not corrode, the wood surrounding the fastener may fail. The vessel can literally "stew in its own juices." It probably requires more than 10 years to produce conditions that can cause some loss in strength to the wood, and severe strength loss has been noted in wood vessels after 20 years' service. Figure 2 shows some planking removed from a 20-year-old vessel. The wet hull planking was fastened to internal silicon bronze structural straps that were protected cathodically. Salts with a pH of 11 were found in the wood in contact with the bronze where the wood deteriorated.

#### **Corrosion of Metals in Preservative-Treated Wood**

Where long service life in soil or wet conditions is required, wood is treated with oil type preservatives or waterborne salt preservatives. The oil type and



*FIG. 2.—Hull plank from 20 year old wooden ship shows wood degradation around silicon bronze lag bolts. The lag bolts held a silicon bronze brace to the plank; brace and bolts were connected to ship's cathodic protection system.*

waterborne preservatives create significantly different corrosive conditions around metal fasteners.

### *Oil Type Preservatives*

Corrosion of metals in oil type preservatives is usually not a problem except in railroad ties. This inhibition of corrosion of metal in oil type treated wood is probably due to the presence of heavy oils that tend to coat the surfaces of the fasteners. In wood bridge decks, steel dowels are suitable for use in wood treated with preservatives in heavy oils [13]. In wharf and shoreline bulkhead construction where metals are exposed to salt water, hot dip galvanized steel usually is recommended. Corrosion of the metal fasteners within the wood is inhibited for these uses because the holes are most often drilled prior to pressure impregnation of the preservative, whereas with rail ties the holes are drilled after treatment and the rail spikes are in contact with moist, untreated wood.

### *Waterborne Preservatives*

Waterborne preservatives containing copper salts can cause corrosion due to small quantities of soluble copper ions. Corrosion in moist treated wood is probably directly related to the presence of copper ions because of deposition by the copper ions on the more electronegative steel fastener. This results in a galvanic couple consisting of the fastener, moist wood, and the copper metal deposited on the fastener.

Corrosion rates also are related to electrical conductivity of the moist wood which is influenced by the moisture level and the presence of soluble preservative by-product salts. Under conditions of low moisture content, corrosion will be negligible; however, when the moisture content of the treated wood approaches about 20 percent, the electrical conductivity increases to where corrosion can occur. The preservative by-product salts can result from the various forms of the chemical ingredients used in the chromated copper arsenate (CCA) preservative. For instance, the CCA preservative can be made from a mixture of potassium dichromate, copper sulfate, and arsenic acid, or from a mixture of chromium trioxide, copper carbonate, and arsenic acid. The former mixture will result in a preservative by-product of potassium sulfate which will increase the electrical conductivity, whereas the latter will result in a by-product of carbon dioxide that will dissipate and not affect the conductivity.

Experience has shown that above-ground waterborne salt preservative-treated crossarms on utility poles do not present corrosion problems to hot dip galvanized steel. Treated test stakes with zinc identification tags held in place with galvanized nails above ground do not show corrosion after more than 30 years' exposure.

A search of the literature showed that the corrosion of certain metals could be a problem in waterborne salt-treated wood in contact with soil when the moisture level of the wood was high [1]. This indication of corrosion along with the knowledge that the presence of copper ions could result in the galvanic corrosion of metals electronegative to copper led to a recent Forest Products Laboratory study on the corrosion of several metals in waterborne salt-treated wood.

**Procedure**—The study consisted of nailing clean, weighed nails in 230-mm-long pieces of southern yellow pine wood treated with ammoniacal copper arsenate (ACA) and two formulas of chromated copper arsenate (CCA I and CCA II) to meet the specifications for waterborne salt preservative-treated wood for use in wood house foundations for homes and offices [14]. The wood was weighed before and after preservation treatment to ensure the proper loading of the preservative. The CCA preservatives were made with chromium trioxide, copper carbonate, and arsenic acid so that no soluble preservative precipitation reaction by-product remained in the treated wood. The treated wood was kiln dried.

Nails were chosen to represent metals, alloys, and coatings from among those commercially available. Four nails of each type were driven into each 230-mm-long specimen. Specimens containing each nail sample were made for inspection at 1- and 3-year exposure plus an additional specimen for future inspection. Products from individual companies were not compared.

The exposure conditions were either to bury the specimens in soil at the Madison exposure test site or expose them to 95 to 100 percent relative humidity at 27°C (80°F).

After 1 and 3 years' exposure, nails were removed from the test specimens by sawing across the grain close to the nail and splitting the wood along the grain. The nails were cleaned by a recommended procedure of abrading with a rubber stopper to remove corrosion products [15]. Chemical methods of corrosion-product removal were not used because of the coatings on the steel nails.

During these procedures, individual nail identification could be maintained by location of the nails in the numbered wood specimens. The nails were dried, weighed, and the percent weight loss was calculated.

**Results**—From the data in Table 1, and visual examination of the nails, the following statements can be made about each of the four groups of nails:

(a) With Monel and AISI types 316 and 304 stainless steels, only slight corrosion was noticed. Weight loss and appearance were about the same for each alloy and exposure except for some shallow pitting on the shank of the Monel nails in the CCA I-treated wood.

(b) The Type B silicon bronze and ETP copper nail shanks had a coating of green corrosion product. Weight loss and appearance are about equal in all exposures.

(c) Most of the coatings were gone from all of the steel nails coated with

TABLE 1 – Weigh loss of various nails after 1 and 3 years, percent.

Nails	Soil						100 % Relative Humidity, 27°C (80°F)					
	CCA I		CCA II		ACA		CCA I		CCA II		ACA	
	1	3	1	3	1	3	1	3	1	3	1	3
<b>Monel</b>	0.1	0.11	0.06	0.07	<0.02	<0.02	0.1 I	0.36	0.08	0.20	0.02	<0.02
Type 316 stainless steel	0.06	0.06	<0.02	0.05	0.04	<0.02	0.06	<0.02	0.03	0.03	0.02	0.02
Type 304 stainless steel	<0.02	10.02	<0.02	0.03	<0.02	<0.02	0.06	<0.02	0.05	<0.02	0.03	10.02
Type B silicon bronze	0.16	0.30	0.30	0.37	0.10	0.17	0.01	0.08	0.14	<0.02	0.16	0.05
ETP copper	0.13	0.24	0.20	0.30	0.09	0.10	0.02	0.10	0.15	0.05	0.12	0.03
Hot dip galvanized steel	0.7	1.3	1.4	2.2	5.8	8.3	1.0	3.6	0.7	2.3	8.7	10.9
Mechanically coated zinc on steel	1.9	2.7	1.9	2.8	6.2	13.0	3.4	5.3	3.8	4.4	7.4	17.5
Electrolytically coated zinc on steel	1.3	2.8	1.8	2.9	3.2	10.7	2.1	6.9	1.5	3.1	8.8	6.9
Cadmium coated steel	1.4	2.6	1.9	2.9	7.7	8.9	3.0	5.0	3.0	5.7	8.4	18.3
Tin-cadmium coated steel	1.2	2.1	1.9	2.5	4.1	5.2	2.2	12.4	3.0	4.0	6.9	12.4
5056 aluminum	2.0	3.0	2.6	3.9	1.7	2.9	0.4	1.4	1.8	0.6	0.1	5.4

NOTE—

CCA I and II – Formulas I and II of chromated copper arsenate preservative.

ACA – Ammoniacal copper arsenate.

zinc, tin-cadmium, and cadmium. Corrosion in ACA-treated wood was much higher than in CCA treated wood. The exposed steel in the head was pitted on all nails.

(d) All of the 5056 aluminum nails sustained pitting corrosion. Nail heads in buried samples showed pinhole pitting in ACA-treated wood and general pitting in CCA-treated wood. All nail shanks exhibited elongated pitting that considerably reduced the cross section of the nails.

Table 1 contains the percent weight loss for each type of nail after 1 and 3 years' exposure in the preservative-treated wood under the two exposure conditions. The data indicate that most of the nails corrode faster in the 27°C (80°F). 100 percent relative humidity exposure than in the soil exposure. This is as expected because of the lower corrosion rate at the lower outdoor temperature.

The difference in weight losses between the three treatments might be related to the presence of chromates. Chromates often are used as corrosion inhibitors. The chromate content of CCA I is greater than the chromate content of CCA II. ACA treatment contains no chromate. Because of the relative chromate content then, the weight losses of metals in the other CCA formulation (CCA III) could be expected to be between those of CCA I and CCA II.

The data on weight loss show that the stainless steels, Monel, copper, and silicon bronze nails corrode much less than do the coated steel and aluminum nails. This is as predicted from the galvanic series of corrosion potential of metals and alloys [16]. Thus the galvanic series can provide a preliminary estimate of the tendency for corrosion when selecting fastener materials for wood treated with copper salts that will be exposed to below-ground or damp conditions. It appears that metals anodic to copper in the galvanic series are subject to corrosion, whereas metals cathodic to copper do not corrode or at least show only slight corrosion after 3 years' exposure in the preservative-treated wood.

In an attempt to use a rapid technique to estimate corrosion tendencies of metals in the moist preservative-treated wood, the corrosion rate of aluminum was determined by a rapid electrochemical corrosion test [17]. The procedure involves the determination of anodic and cathodic polarization curves between the moist wood sample containing the aluminum fastener and a half cell as current was passed through the structure from a working electrode. From these curves, a corrosion behavior diagram can be constructed that completely describes an alloy's corrosion characteristics in a given environment. The results can be converted to corrosion rate in the media and temperature range that represents actual service environments. The corrosion rates measured for aluminum nails in moist wood at room temperature were:<sup>3</sup>

<sup>3</sup>Personal communication, Scott, J. R. and Lindberg, R. I., Metallurgical Research Division, Reynolds Metals Co., Richmond, Va. 23219.

	Micrometers per year. $\mu\text{m}/\text{year}$
ACA	584
CCA-I	381
CCA-II	660

### Corrosion of Metals in Fire-Retardant-Treated Wood

The fire performance of wood products is improved by treating with fire-retardant chemicals such as boric acid, borax, ammonium sulfate, aluminum sulfate, and mono- and di-ammonium phosphates. These compounds are corrosive to metals in humid or moist environments. Because some of them are also hygroscopic, they can be aggressive at low relative humidities, too. The corrosiveness of a fire-retardant-treated product varies with the formulation used. Some formulations include corrosion inhibitors such as sodium dichromate and ammonium thiocyanate.

Several studies have been conducted to determine the corrosiveness of the fire-retardant treatment on various fasteners and on the strength of joints exposed to certain environments. These are well described by Graham et al [1]. A more recent report on the corrosiveness of fire-retardant-treated cellulose insulation indicates a wide range of pH and corrosiveness to SAE 1018 carbon steel, 2024-0 aluminum, and Type K copper by 19 U.S. commercial cellulose insulation products [18]. There the pH of a water slurry of a group of insulation specimens varied from 4.0 to 8.2.

Corrosiveness was measured in accordance with a slightly modified test given in Section 10.7 of ASTM Specification for Cellulosic Fiber (Wood-Base) Loose-Fill Thermal Insulation (C 739 - 73) at the specified conditions of 49°C (120°F) and 96 percent relative humidity for 30 days. The measured general corrosion rates for aluminum ranged from 50 to 390  $\mu\text{m}/\text{year}$ ; for copper, from nil to 780  $\mu\text{m}/\text{year}$ ; and for steel, from 150 to 2240  $\mu\text{m}/\text{year}$ . The corrosion rates of control specimens exposed only to the test atmosphere were 180, 50, and 50  $\mu\text{m}/\text{year}$ , respectively. Maximum pit depth of aluminum during the test ranged from 150 to 1070  $\mu\text{m}$ . For the aluminum control, the maximum pit depth was 380  $\mu\text{m}$ . These corrosion rates did not correlate with measured chemical composition or pH. Eleven insulation specimens produced excessive general corrosion, primarily of steel, and most specimens produced excessive pitting of aluminum.

There have been no reports of corrosion with the nonleachable type of fire-retardant-treated wood that is recommended for wood exposed to weather. This is probably due to the fact that the fire-retardant chemicals are of an organic nature rather than in salt form in the moist wood.

The general recommendations for protection and use of fire-retardant-treated wood products in contact with metals is to keep them protected from

moisture in storage. and use where relative humidity is maintained below about 80 percent. Wood products that are treated with chemicals in solution should be redried prior to use with metals. If high relative humidities are expected, plastic-coated or stainless steel fasteners should be considered. However. the long-term effect of the fire-retardant chemicals on the stainless steels has not been determined.

### Conclusions

The possibilities and consequences of corrosion of the metals and weakening of the adjacent wood should be considered when using metals and wood in moist or damp environments. The literature indicates that fire-retardant-treated wood is corrosive to many common construction metals and that fastener materials should be selected carefully when fire-retardant-treated wood products are subject to moist environments.

Conclusions from a 3-year study of the corrosion of metals in waterborne salt-treated wood indicate the following:

1. Corrosion of metal in the treated wood is predictable, and that metals used in moist ACA- and CCA-treated wood where long service life is desired should be selected from those metals that are cathodic to copper in the galvanic series.
2. Copper, silicon bronze, and stainless steel Types 304 and 316 fasteners appear suitable for use in moist ACA- and CCA-treated wood where long service life is required.
3. Aluminum and zinc, tin-cadmium, and cadmium-coated steel nails do not appear suitable for use in moist ACA- and CCA-treated wood where long service life is required.

### *Acknowledgment*

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