

Introduction

This GalvInfoNote explains how hot-dip galvanneal differs from hot-dip galvanize. The hot-dip galvanizing process is explained in GalvInfoNote 2.1. In manufacturing galvanneal, the main differences in the process are that a lower level of aluminum (typically 0.11% to 0.14%) is used in the zinc bath, and the moving, zinc-coated strip is reheated immediately after it passes the air-wiping step above the zinc bath. By heating the strip to between 935 - 1050°F (500 - 565°C), and holding at this temperature for a few seconds, the zinc coating, by way of diffusion, alloys with the iron in the steel. The end result is that the coating is converted to layers of zinc-iron intermetallic compounds with a bulk composition of approximately 90% zinc and 10% iron. These are averages, as the iron percentage varies throughout the coating thickness, from as low as ~6% at the surface, to as high as ~23% at the steel interface. Galvanneal coatings have no free-zinc present and have a low-lustre matte appearance, versus the metallic sheen of galvanized coatings. The final bulk iron concentration depends primarily on the heating cycle, since the rate of diffusion is a function of time and temperature. The zinc and steel chemistries can also affect the alloying behavior, but they are secondary to the heating cycle.

The differences in characteristics and performance between galvanneal coatings versus galvanize coatings are explained below.

Coating Composition

A galvanize coating is essentially pure zinc, with between 0.20 and 0.50% bulk aluminum, although it is highly concentrated in the thin inhibition layer next to the steel. The aluminum is present, not to affect the corrosion performance, but to provide adhesion between the coating and the steel substrate when the sheet is eventually formed. See GalvInfoNote 2.4 for an explanation of the role of aluminum in continuous hot-dip galvanizing.

Galvanneal coatings contain 9 -12% bulk iron, along with a small amount of aluminum, which is spread more uniformly through the coating thickness than in the case of galvanize. The iron in galvanneal coatings is definitely not uniformly distributed, however, as it is combined with zinc in 3 distinct zinc-iron phases. These phases are shown in Table 1, along with their iron and aluminum contents.

Table 1 Galvanneal Phases and Compositions

Alloy Layer	% Fe	%Al
Zeta (ζ) FeZn ₁₃	5.2 – 6.1	0.7
Delta (δ) FeZn ₁₀	7.0 – 11.5	3.7
Gamma (Γ) Fe ₃ Zn ₁₀	15.8 – 27.7	1.4

The phases in Table 1 are shown in the order that they occur in the coating, with the high-iron gamma layer next to the steel substrate. It is also important for good appearance and press formability that the top zeta layer contain no less than about 5% iron or there will be a risk of free zinc on the surface. The

higher aluminum content of galvaneal coatings is a result of its diffusion outward from the inhibition layer next to the steel.

Figure 1 is a micrograph of a cross section of a galvaneal coating showing the three alloy phase layers.

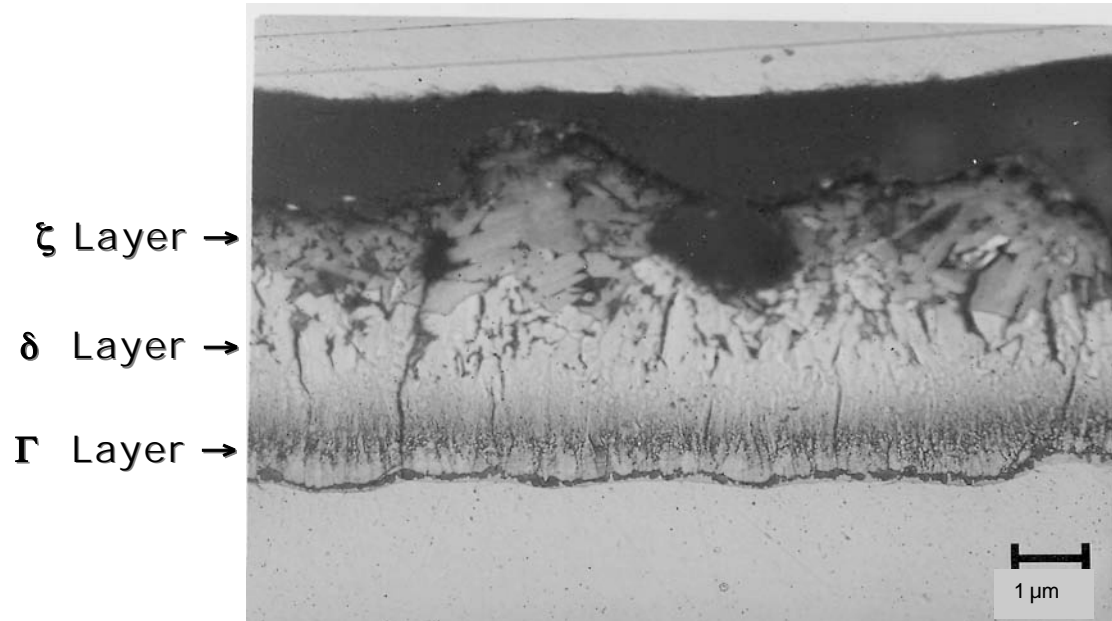


Figure 1 Cross-section of galvaneal coating showing the gamma (Γ), delta (δ) and zeta (ζ) alloy layers

Galvaneal coatings are hard and brittle. During bending and press forming, coating cracks and powdering are always present to some degree. Each coating line must develop practices to produce the optimum coating properties for the particular end use, in order to balance performance in forming versus coating line throughput.

Production of Galvaneal

The moving strip, with the still liquid zinc coating, enters the galvaneal furnace about 10-15 feet above the gas wiping knives. Before the zinc can solidify, reheating of the strip begins. As the strip temperature rises, the zinc-iron diffusion reaction restarts and breaks down the aluminum-zinc-iron inhibition layer that formed in the zinc pot at the steel zinc interface. After 5-7 seconds of heating and up to about 10 seconds of soaking, enough iron diffuses into the coating to convert it to a dull matte gray appearance.

Coating lines built since the early 1990s use induction galvaneal furnaces. Typically they have 3 or more zones, which can reheat the strip from about 865°F (463°C) to 1050°F (565°C) in the few seconds available. Following the heating furnace zones is an electrically heated holding zone that is used to optimize the iron content of the coating. Older galvaneal coating lines use gas-fired furnaces, with which it can be more difficult to obtain a well-controlled alloying reaction. Induction galvannealing is inherently different than the convection/radiation version since, with the former, the heat for diffusion comes from within the strip, not externally as with the latter process.

The reactions that convert a liquid zinc coating to a solid zinc-iron coating begin at the steel interface and are dependent on a number of factors. In approximate order of importance they are: heating time and temperature, percent aluminum in the coating, coating bath temperature, steel grade, coating weight, and line speed. These variables are not all necessarily independent and each coating line has to determine the necessary protocol to produce a product for a particular end use. For instance, a higher Al in the

coating requires a higher reheating temperature and/or a longer soaking time. Too high a temperature and too low an Al will result in high iron and excess powdering. Stabilized IF grades react faster than plain carbon steels. Steels with higher phosphorous levels react slower in the galvannealing furnace than low P steels.

Figure 2 is a schematic representation of the galvannealing process.

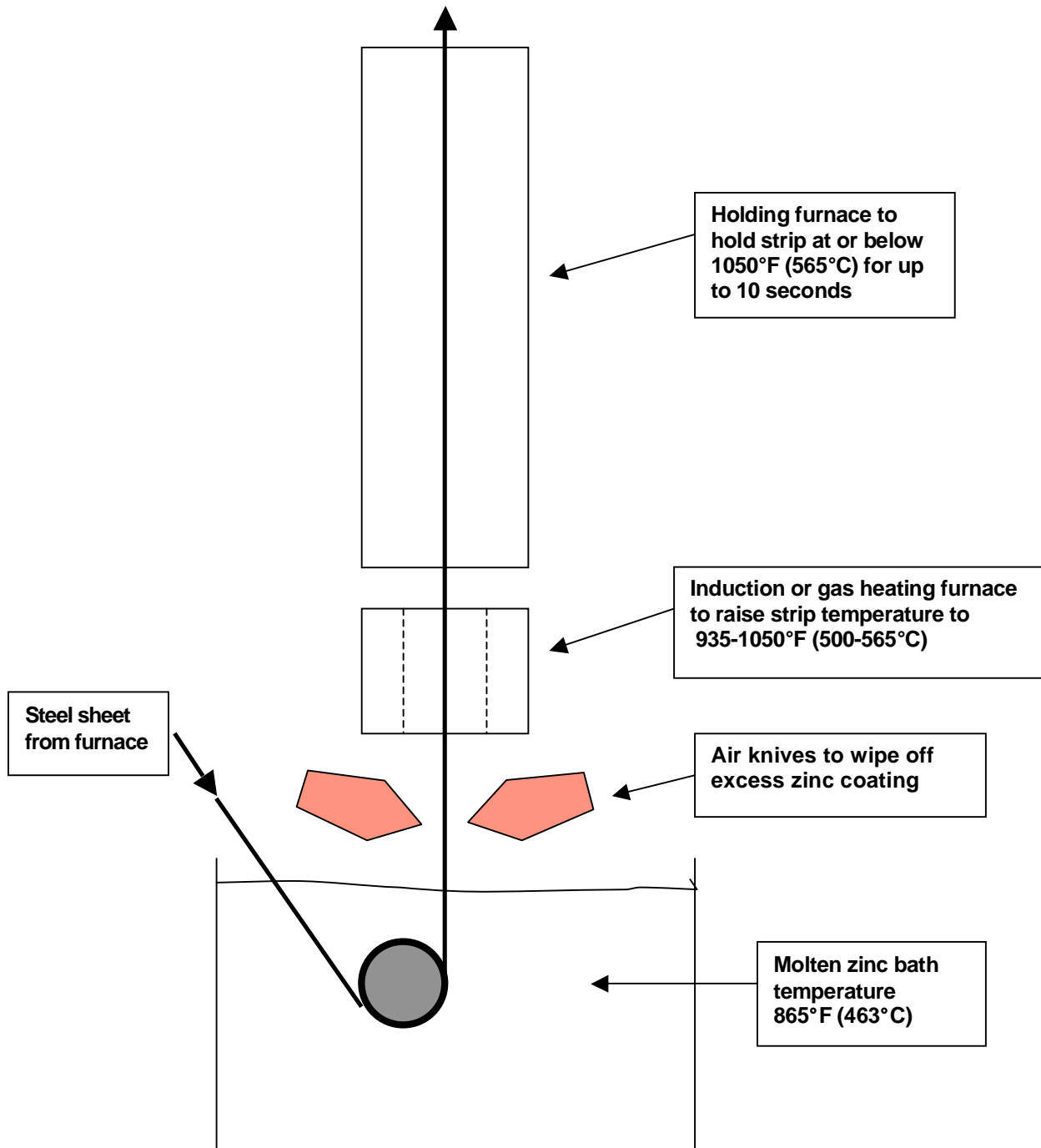


Figure 2 The Galvannealing Process

The moving sheet is immersed in the zinc bath where a thin inhibition alloy layer forms at the zinc-steel interface. As the strip emerges from the bath it drags excess zinc with it, which the air knives remove to obtain the desired coating weight. The still molten zinc coating is converted to zinc-iron alloy layers in the heating and holding furnaces.

Figure 3 depicts the stages the coating goes through during its conversion from zinc to zinc-iron.

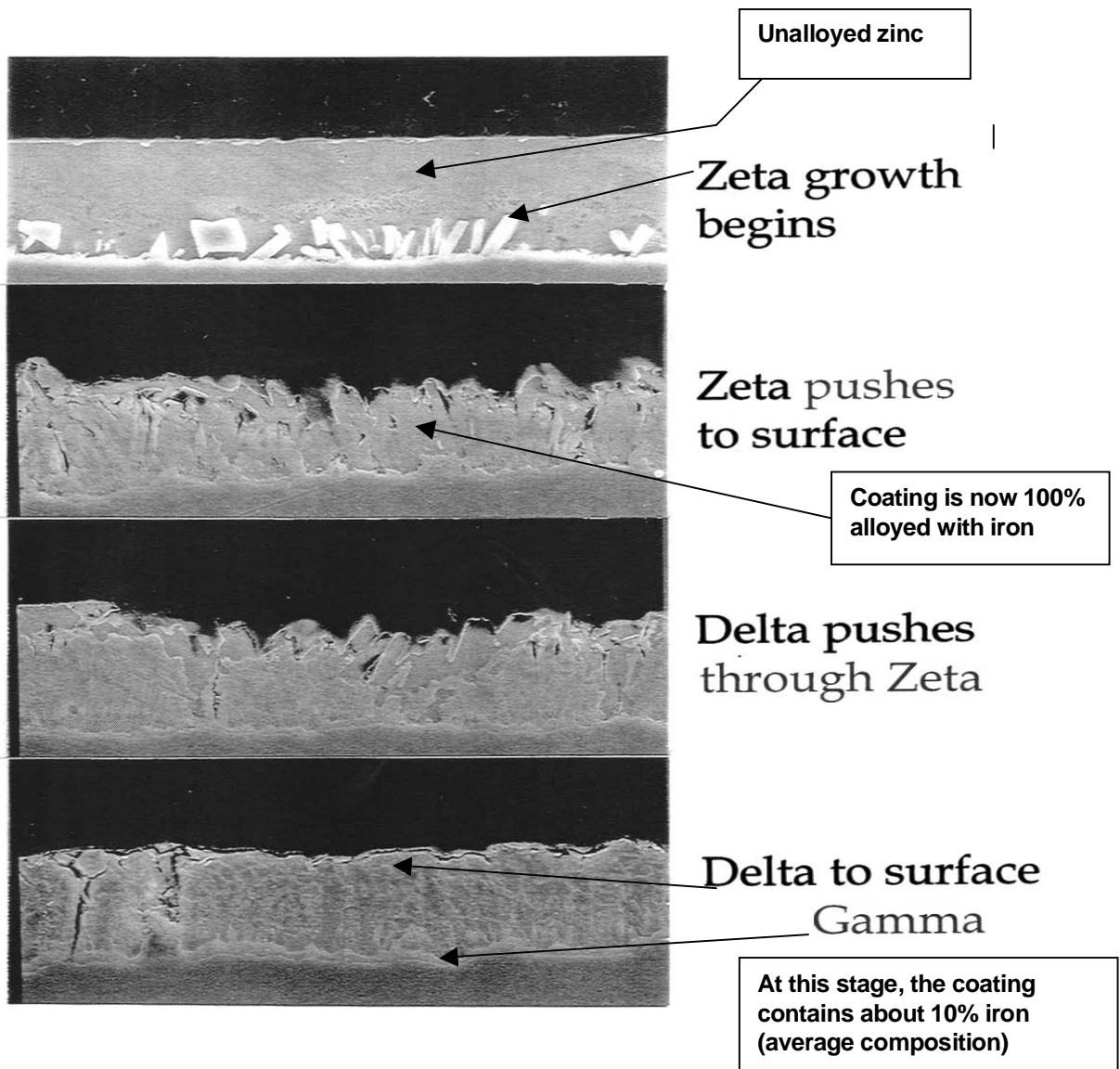


Figure 3 The Stages of Alloying Between Steel Sheet and Molten Zinc Coating to Produce "Galvanneal"

Coating Weldability, Paintability, Formability and Adherence

Two primary benefits of using galvaneal rather than galvanize are:

- Improved spot-weldability
- Ease of painting and improved coating adhesion

Zinc-iron alloy coatings generally have better spot welding characteristics than pure zinc coatings¹. The coating's higher electrical resistance, along with its higher hardness and higher melting point, allow good welds to be obtained at lower currents with longer electrode life, to the extent that galvanealed sheet spot-welds very much like cold rolled sheet.

Performance of galvaneal under paint is synergistically improved because of the excellent bond formed between the paint and the surface of the coating. The reason for the good bond is evident in Figure 4 – the paint can “mechanically lock” with the zinc-iron crystals on the surface. This is why galvaneal coatings can be painted directly without the need for a primer. Compared with a galvanized product, galvaneal generally exhibits less undercutting corrosion beneath paint at exposed edges, scratches, or other defects in the paint. To achieve maximum corrosion protection, galvaneal is usually treated with zinc phosphate before painting.

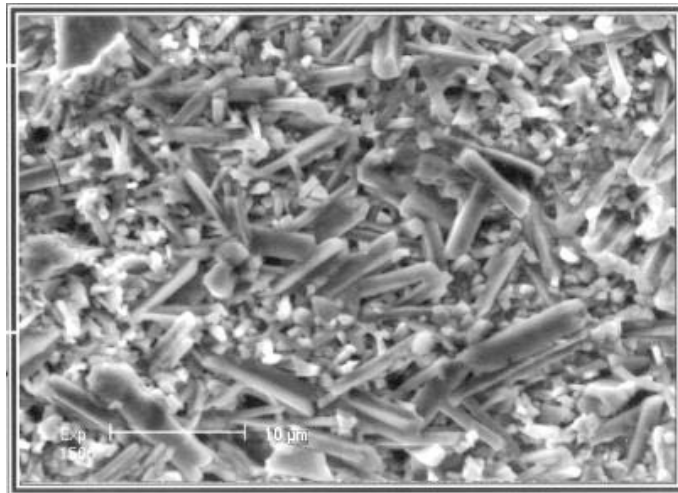


Figure 4 Surface of Galvaneal – Showing Zinc-Iron Alloy Crystals (magnification ~ 2700X)

A galvanize coating is quite soft, and easily scratched. A galvaneal coating is very hard, and thus not as easily scratched when handling. The harder zinc-iron alloy powders on deformation, unlike pure zinc coatings, which can gall and flake¹.

The good frictional behaviour and ductility of zinc, combined with the excellent adhesion achieved between the coating and the steel, allows galvanized sheet to be formed into many intricate shapes without any loss in coating adhesion. In fact, because the coating is soft, care needs to be exercised to prevent flaking resulting from galling.

Even though the galvaneal alloying reaction results in a hard, relatively brittle coating, it can be bent, stretched and drawn when correct sheet manufacturing and part forming procedures are used. Many parts made from galvanealed sheet require a deep drawing operation. When deep drawn, galvanealed sheet typically exhibits some “powdering” of the coating as a result of high compressive strain that can occur during the forming operation. By proper control of the steel manufacturers’ processing practices, combined with the proper setup of the drawing dies, and the use of appropriate drawing lubricants, the amount of powdering can be minimized and excellent performance can be achieved.

The powdering of a galvanized coating during forming is a function of many parameters, mostly relating to the steel manufacturing practices covered previously. The most important characteristic of the coating that affects the powdering tendency is the coating thickness. The amount of powdering rises directly as the thickness increases. For this reason, the maximum coating weight for galvanized is restricted to A60 (0.60 oz/ft²) [ZF180 (180 g/m²)]. For many applications, an A60 coating weight is too thick to provide acceptable powdering performance, and many users specify A40 (0.40 oz/ft²) [ZF120 (120 g/m²)], or less. In fact, most automobile applications of galvanized use the equivalent of about an A30 [ZF90] coating. The tendency for A60 to powder should be considered when selecting a coating weight.

Generally, there are no significant differences in the properties of the steel substrate whether it is galvanized or galvanized. Any differences in forming behaviour (splits, etc.) are usually related to the different nature of the two metallic coatings. For example, the substantial difference in coating hardness can necessitate changes to the stamping parameters, i.e., die type, die clearances, hold-down forces, lubrication type, etc.

Corrosion Performance

The thickness of a galvanized coating has a direct influence on the corrosion performance and life of the product, i.e., the thicker the coating, the longer its life. See GalvInfoNote 3.1 – “How Zinc Protects Steel” for more information.

The corrosion performance of a galvanized coating is more complicated than its galvanized counterpart. Almost all applications of galvanized sheet involve painting after fabricating. The primary reason is that, when unpainted, the presence of 10% iron in the coating can lead to a “reddish-colored” corrosion product. The color is related to corrosion of the iron within the coating and does not necessarily signify that corrosion of the steel substrate is occurring. This discoloration due to the iron in the coating is purely a cosmetic effect.

Nevertheless many users find this staining unacceptable, thereby requiring most applications for galvanized be painted after fabrication. For this reason, most corrosion studies of galvanized relate to it being painted. Since paint systems have a direct influence on product life, the corrosion performance of galvanized is generally not compared with bare (unpainted) galvanized. The importance of the galvanized coating thickness is often revealed at sheared edges or scratches, etc, i.e., places where the steel and metallic coating are directly exposed to the corroding environment. At such discontinuities, a thicker coating can improve resistance to “undercutting” the paint film, i.e., a thicker galvanized coating can slow down degradation of the paint, as evidenced by edge “creep back” corrosion and eventual total loss of paint adhesion. To maximize service life, it is therefore advisable to use as thick a galvanized coating as potential powdering problems will allow.

Considering the relative corrosion rates:

- A pure zinc coating (galvanized) provides a high degree of galvanic protection to exposed steel such as at sheared edges and scratches.
- A galvanized coating is about 10% less galvanically active in most environments because it contains 10% iron. Its bare corrosion rate may, in fact, be less than pure zinc but is masked by the “reddish-colored” corrosion products that form on the surface from the iron in the coating.
- The more galvanically active galvanized coatings could be quickly consumed when acting as a galvanic protector to any exposed steel. The less galvanically active galvanized coatings do not offer as much galvanic protection, and therefore are not as rapidly consumed during the corrosion process. It is interesting to note that over the last 2 decades, automotive galvanized coatings equivalent to about A30, have performed just as well as approximate G50 galvanized coatings with respect to the corrosion resistance of painted outer auto body panels.

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- The specific needs of the application and the corrosion performance requirements dictate which coating will perform best. Other requirements for the application, such as weldability and the specific capabilities of each product manufacturers' paint shop need to be considered when deciding which product is best for a given situation.

Which Product to Use

When considering whether to use galvanize or galvalume for a specific application, find the answer to such questions as:

- What are the corrosion demands of the end use and the environment? Coating thickness is the primary consideration.
- Is spot welding involved? Galvalume might perform better.
- Is the product going to be used unpainted? In most cases, galvanize is preferred.
- Is deep drawing involved? Before applying galvalume, stamping trials may need to be conducted in order to assure that the amount of powdering is acceptable.

In almost all applications, there is more than one issue involved. The correct product recommendation by the producer requires in-depth consideration of all processing steps included in manufacturing, plus knowledge of end-use requirements.

Reference:

- 1) J. P. Landriault, F.W. Harrison: CIM Bulletin, August 1987, pp. 71-78

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