

~~ISO/DTR PRF TR 22824:2023(E)~~

~~IIW Commission II~~

~~Secretariat: IIW~~

~~Date: 2023-08-25~~

## Welding — Best practices for specification and measurement of ferrite in stainless steel weld metal

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## Contents

**Foreword** ..... Error! Bookmark not defined.

**Introduction** ..... Error! Bookmark not defined.

**1 Scope** ..... Error! Bookmark not defined.

**2 Normative references** ..... Error! Bookmark not defined.

**3 Terms and definitions** ..... Error! Bookmark not defined.

**4 Metallurgical phenomena of ferrite in stainless steel weld metal** Error! Bookmark not defined.

**4.1 General** ..... Error! Bookmark not defined.

**4.2 Solidification mode** ..... Error! Bookmark not defined.

**4.3 Solid state phase transformation of ferrite to austenite** ..... Error! Bookmark not defined.

**4.4 Constitution diagrams** ..... Error! Bookmark not defined.

**4.5 Effects of welding conditions on ferrite** ..... Error! Bookmark not defined.

**4.6 Alpha prime and intermetallic phase formation** ..... Error! Bookmark not defined.

**4.7 Chromium nitrides and secondary austenite** ..... Error! Bookmark not defined.

**4.8 Postweld heat treatment** ..... Error! Bookmark not defined.

**5 Effects of ferrite variations on service performance of stainless steel weld metal** ..... Error! Bookmark not defined.

**5.1 General** ..... Error! Bookmark not defined.

**5.2 Tensile properties at ambient temperatures** ..... Error! Bookmark not defined.

**5.3 Toughness** ..... Error! Bookmark not defined.

**5.4 Resistance to chloride stress corrosion cracking (CSCC)** ..... Error! Bookmark not defined.

**5.5 Susceptibility to corrosion in certain media** ..... Error! Bookmark not defined.

**5.6 Creep resistance** ..... Error! Bookmark not defined.

**6 Measurement of ferrite in stainless steel weld metal** ..... Error! Bookmark not defined.

**6.1 General** ..... Error! Bookmark not defined.

**6.2 Considerations in ferrite measurement** ..... Error! Bookmark not defined.

**6.3 Metallographic percent ferrite by optical methods** ..... Error! Bookmark not defined.

**6.4 Metallographic measurement of ferrite by EBSD** ..... Error! Bookmark not defined.

**6.5 Ferrite measurement by x-ray diffraction** ..... Error! Bookmark not defined.

**6.6 Ferrite measurement by electrochemical dissolution of austenite** Error! Bookmark not defined.

**6.7 Ferrite measurement by saturation magnetization** ..... Error! Bookmark not defined.

**6.8 Ferrite measurement by magnetic attraction** ..... Error! Bookmark not defined.

**6.9 Measurement by magnetic permeability (magnetic induction)** Error! Bookmark not defined.

**6.10 Location and volume of measurement** ..... Error! Bookmark not defined.

**6.11 Measurement in the HAZ** ..... Error! Bookmark not defined.

**6.12 Reproducibility of measurement** ..... Error! Bookmark not defined.

**6.13 Correlations between Ferrite Number and ferrite percent** ..... Error! Bookmark not defined.

**7 Specification of ferrite in stainless steel weld metal** ..... Error! Bookmark not defined.

**7.1 General** ..... Error! Bookmark not defined.

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7.2 **Non-magnetic requirements**..... Error! Bookmark not defined.  
7.3 **Service environments in which ferrite is aggressively attacked**..... Error! Bookmark not defined.  
7.4 **Cryogenic applications requiring weld metal toughness** ..... Error! Bookmark not defined.  
7.5 **High temperature service**..... Error! Bookmark not defined.  
7.6 **Dissimilar welds**..... Error! Bookmark not defined.  
7.7 **Buffer layers and cladding**..... Error! Bookmark not defined.  
7.8 **Duplex ferritic-austenitic welds** ..... Error! Bookmark not defined.  
8 **Outliers in ferrite measurement**..... Error! Bookmark not defined.  
9 **Conclusions**..... Error! Bookmark not defined.  
**Bibliography** ..... Error! Bookmark not defined.

Foreword — v  
Introduction — vi  
1 — Scope — 1  
2 — Normative references — 1  
3 — Terms and definitions — 1  
4 — Metallurgical phenomena of ferrite in stainless steel weld metal — 2  
4.1 — General — 2  
4.2 — Solidification mode — 2  
4.2.1 — General — 2  
4.2.2 — A solidification mode (austenitic) — 3  
4.2.3 — AF solidification mode (primary austenite) — 3  
4.2.4 — FA solidification mode (primary ferrite) — 3  
4.2.5 — F solidification mode (ferritic) — 4  
4.2.6 — Mixed solidification modes — 4  
4.3 — Solid state phase transformation of ferrite to austenite — 5  
4.3.1 — A solidification mode alloys — 5  
4.3.2 — AF solidification mode alloys — 6  
4.3.3 — FA solidification mode alloys — 6  
4.3.4 — F solidification mode alloys — 7  
4.4 — Constitution diagrams — 7  
4.5 — Effects of welding conditions on ferrite — 11  
4.5.1 — General — 11  
4.5.2 — Welding conditions which affect chemical composition — 11  
4.5.3 — Welding conditions which don't affect chemical composition — 12  
4.6 — Alpha prime and intermetallic phase formation — 13  
4.7 — Chromium nitrides and secondary austenite — 13  
4.8 — Postweld heat treatment — 13  
5 — Effects of ferrite variations on service performance of stainless steel weld metal — 15

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5.1 General 15

5.2 Tensile properties at ambient temperatures 15

5.3 Toughness 16

5.4 Resistance to chloride stress corrosion cracking (CSCC) 16

5.5 Susceptibility to corrosion in certain media 17

5.6 Creep resistance 17

6 Measurement of ferrite in stainless steel weld metal 18

6.1 General 18

6.2 Considerations in ferrite measurement 18

6.3 Metallographic percent ferrite by optical methods 19

6.4 Metallographic measurement of ferrite by EBSD 20

6.5 Ferrite measurement by x-ray diffraction 20

6.6 Ferrite measurement by electrochemical dissolution of austenite 20

6.7 Ferrite measurement by saturation magnetization 20

6.8 Ferrite measurement by magnetic attraction 20

6.9 Measurement by magnetic permeability (magnetic induction) 21

6.10 Location and volume of measurement 22

6.11 Measurement in the HAZ 23

6.12 Reproducibility of measurement 23

6.13 Correlations between Ferrite Number and ferrite percent 24

7 Specification of ferrite in stainless steel weld metal 25

7.1 General 25

7.2 Non-magnetic requirements 25

7.3 Service environments in which ferrite is aggressively attacked 25

7.4 Cryogenic applications requiring weld metal toughness 26

7.5 High temperature service 26

7.6 Dissimilar welds 26

7.7 Buffer layers and cladding 27

7.8 Duplex ferritic-austenitic welds 27

8 Outliers in ferrite measurement 27

9 Conclusions 29

Bibliography 31

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## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part-1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part-2 (see [www.iso.org/directives](http://www.iso.org/directives)).

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This document was prepared by ~~the~~ Technical Committee IIW, International Institute of Welding, Commission II, Arc welding and Filler Metals.

This second edition cancels and replaces the first edition (ISO/DTRTR 22824:2003), which has been technically revised.

The main changes compared to the previous edition are that as follows:

- ~~—~~ ~~Metallurgical Phenomenon~~ the metallurgical phenomenon of Ferrite ~~ferrite has been~~ addressed;
- ~~—~~ ~~Methods~~ methods of Ferrite Measurement ~~are~~ ferrite measurement have been addressed;
- ~~—~~ ~~Best Practice~~ best practice for Reasonable ~~reasonable~~ and Effective ~~Specification~~ effective specifications for Ferrite ~~is~~ ferrite has addressed;
- ~~—~~ ~~Best Practice~~ best practice for Dealing ~~dealing~~ with Outliers ~~outliers~~ in Ferrite Measurement ~~is~~ ferrite measurement has been addressed;
- ~~—~~ ~~The~~ the list of References ~~references~~ has been ~~Significantly Expanded~~ significantly expanded.

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## Introduction

This document was prepared by the International Institute of Welding, Commission II, through its Subcommittee II-C, Arc Welding and Filler Metals, in cooperation with Commission IX through its Subcommittee IX-H, Welding of Stainless Steels and Nickel Base Alloys, on behalf of ISO/TC 44/SC 3. It constitutes the considered judgement of the experts on measurement and specification of ferrite in nominally austenitic and duplex ferritic-austenitic stainless steel weld metals.

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# Welding — Best practices for specification and measurement of ferrite in stainless steel weld metal

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## 1 Scope

This document describes a best practice, based on the experience of experts, for setting appropriate requirements, in specifications and other standards and contract documents, on ferrite content of nominally austenitic or duplex ferritic-austenitic stainless steel weld metals. It also describes a best practice on measurement and measurement reproducibility, and deals with outliers in measurement. It considers ferrite in the weld heat-affected zone of duplex stainless steel. It does not consider specification or measurement of ferrite in ferritic stainless steels nor in martensitic stainless steels.

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## 2 Normative references

There are no normative references in this document.

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## 3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

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— ISO Online browsing platform: available at <https://www.iso.org/obp>

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— IEC Electropedia: available at <http://www.electropedia.org/>

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### 3.1 stainless steel

any member of a diverse family of alloys containing at least 10,5 % chromium (the minimum chromium content which provides for rust free service in ordinary ambient air free of salt), and often but not always containing substantial nickel, in which the iron content exceeds that of any other element when all other elements are taken at the specification minima for the alloy

### 3.2 austenite

face-centred cubic crystal structure of iron base alloys that is not ferro-magnetic at ambient temperatures

### 3.3 duplex ferritic-austenitic stainless steel

stainless steel base metal or weld metal consisting of a microstructure of approximately equal parts ferrite and austenite, although the ranges of the two phases can be quite broad — often shortened to duplex stainless steel

Note 1 to entry: The ranges of the two phases can be quite broad — often shortened to duplex stainless steel.

### 3.4 ferrite

body-centred cubic crystal structure of iron base alloys that is ferro-magnetic at ambient temperatures

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### 3.5

#### Ferrite Number ~~(FN)~~

##### FN

magnetically determined measure of ferrite content made using an instrument calibrated according to ISO 8249<sup>[1]</sup> ~~the term is always capitalized to signify compliance with the ISO standard<sup>[1]</sup>~~

Note 1 to entry: The term is always capitalized to signify conformance with the ISO standard.

### 3.6

#### ferrite percent

volumetric content of ferrite which can be determined metallographically, by a magnetic instrument, by x-ray diffraction, or by other means

### 3.7

#### martensite

body-centred tetragonal crystal structure of iron base alloys that is ferro-magnetic at ambient temperatures and is formed by a shear transformation from austenite without diffusion

### 3.8

#### nominally austenitic stainless steel

stainless steel base metal or weld metal which consists predominately of austenite but contains a small amount of ferrite when it reaches ambient temperature directly after solidification ~~this~~

Note 1 to entry: This ferrite can transform in whole or in part to austenite during hot working and/or annealing, but will reappear in some form if the steel is once again melted (e.g., by gas tungsten arc welding without filler metal).

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## 4 Metallurgical phenomena of ferrite in stainless steel weld metal

### 4.1 General

The ferrite observed in stainless steel weld metal of a given chemical composition at ambient temperature is the end result of its solidification mode, solid state phase transformations during cooling from solidification temperature, and further solid state phase transformations during reheating cycles caused by deposition of subsequent weld passes and/or by postweld heat treatment.

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In pure iron, solidification takes place at ~~1538~~ 1538 °C as ferrite, commonly called "delta ferrite". Upon cooling, this ferrite transforms to austenite at ~~1394~~ 1394 °C. On further cooling to 912 °C, the austenite transforms back to ferrite, this time commonly termed "alpha ferrite". Certain alloying elements when added to iron promote the austenite phase during solidification. Notable austenite promoters commonly found in stainless steels are nickel, carbon, nitrogen and copper. The addition of about 4,6 % nickel, or more, to pure iron changes the result of solidification from ferrite to austenite.

Certain other alloying elements when added to iron promote the ferrite phase during solidification. Notable ferrite promoters commonly found in stainless steels are chromium, molybdenum and niobium. Less common ferrite promoting elements occasionally found in stainless steels include aluminium, titanium, vanadium and tungsten.

At one time, manganese was thought to be an austenite promoter during solidification. More recently, it has been proven that manganese, at least up to 12 %, is neutral with respect to promoting ferrite or austenite during solidification<sup>[2]</sup>. ~~Manganese~~<sup>[2]</sup> does, however, stabilize austenite with respect to transformation to martensite at much lower temperatures<sup>[2]</sup>,<sup>[3]</sup>.

At one time, silicon was thought to be a ferrite promoter during solidification. The role of silicon is less clear than that of manganese. Experimental work involving weld metal of essentially constant composition except that silicon was varied from 0,34 % to 1,38 % found negligible effect of silicon on weld metal ferrite content<sup>[4]</sup>,<sup>[4]</sup>. However, still higher levels of silicon do appear to promote ferrite.

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## 4.2 Solidification mode

### 4.2.1 General

In stainless steels, two metallurgical phases are possible at temperatures just below the solidus. These two phases are austenite and ferrite. A particular stainless steel could solidify entirely as austenite (A solidification mode), entirely as ferrite (F solidification mode), or as a mixture of austenite and ferrite. The mixed solidification can occur as austenite first, ferrite last (primary austenite or AF solidification mode) or as ferrite first, austenite last (primary ferrite or FA solidification mode).

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The solidification mode is important with regard to weldability of a given stainless steel because it has a profound effect on the tendency for solidification cracking. Solidification cracking could be readily visible in the weld crater or along the weld centreline. But it also could be hidden as longitudinal cracking along the root.

### 4.2.2 A solidification mode (austenitic)

Stainless steel weld metal that freezes in the A solidification mode generally contains no ferrite at the end of solidification and generally has the highest tendency towards solidification cracking of the four possible solidification modes. Successful welding when this solidification mode is expected can require selection of filler metal with unusually low levels of sulphur, phosphorus and other trace elements. It could also or alternately require special welding techniques including deposition of weld metal as small convex runs with low heat input, and overfilling of the crater at the end of each run. In the extreme, grinding of convex runs and crater overfill after each weld run could be required to obtain sound weld metal.

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Austenitic stainless steel base metals and their corresponding weld metals that are high in nickel content generally exhibit the A solidification mode. Examples of weld metals which can be expected to exhibit A solidification mode include 25 20 (310), 18 36-H (330), 27 31 4-Cu L (383), and 20 25 5-Cu L (385).

Some improvement in solidification cracking resistance can also be observed if filler metal of abnormally high manganese content is available. Normal manganese content would be typically in the 1% to 2% range, while abnormally high manganese would typically be in the 3% to 9% range. Examples of A solidification mode filler metals of abnormally high manganese content include 25 20-Mn and 20 16 3-Mn L (316LMn).

### 4.2.3 AF solidification mode (primary austenite)

Stainless steel weld metal that freezes in the AF solidification mode generally forms a small amount of ferrite in the interdendritic spaces between columnar austenite crystals in the last stages of solidification. Some partitioning of alloy elements generally takes place, with ferrite-promoting elements chromium and molybdenum (if the latter is present) concentrating more in the ferrite, and austenite-promoting elements nickel, carbon and nitrogen (if the latter is present) concentrating more in the austenite. Weld metal that solidifies in the AF mode generally has only slightly less tendency for solidification cracking than weld metal that solidifies in the A mode. The same welding techniques and weld metal composition modifications that are beneficial for the A solidification mode are also beneficial for the AF solidification mode.

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At times, AF solidification mode can be found in 19 12 3-L (316L), 25 20 (310) and 20 16 3-Mn L (316LMn) weld metals. AF solidification mode could also be found in diluted weld metals used in cladding and/or dissimilar metal joining when one or more of the base metals is carbon steel or low alloy steel, and filler metal such as 23 12-L (309L) is deposited.

### 4.2.4 FA solidification mode (primary ferrite)

Stainless steel weld metal that solidifies in the FA solidification mode generally forms columnar ferrite grains with a small amount of austenite that forms in the interdendritic spaces during the last stages of solidification. Some partitioning of alloy elements generally takes place, with ferrite-promoting elements chromium and molybdenum (if the latter is present) concentrating more in the ferrite, and austenite-

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promoting elements nickel, carbon and nitrogen (if the latter is present) concentrating more in the austenite. Weld metal that solidifies in the FA mode generally has the highest resistance to solidification cracking of all solidification modes. Such weld metals can generally be deposited without fear of solidification cracking. No special welding techniques or composition modifications are needed to obtain sound weld metal.

Most common nominally austenitic stainless steels and their corresponding filler metals are generally designed to solidify in the FA mode. This includes 19 9-L (308L), 23 12-L (309L), 19 12 3-L (316L) and 19 9-Nb (347). Although ferrite might not be detected in the corresponding base metals, due to solid state phase transformation during hot working and annealing of the base metal, ferrite generally reappears when these base metals are autogenously welded. This is due to the steel mills manipulating the base metal composition to obtain FA solidification which improves yield of quality steel during hot working.

Many nominally martensitic stainless steel weld metals, and their corresponding base metals, solidify as FA, including 13 (410), 13 4 (410NiMo), 420 and 17-4PH, but these are outside the scope of this document.

#### 4.2.5 F solidification mode (ferritic)

Stainless steel weld metal that solidifies in the F solidification mode contains no austenite when solidification is complete and is generally much more resistant to solidification cracking than weld metal of the A or AF solidification mode, but not as resistant as weld metal of the FA solidification mode. With F mode compositions, if solidification cracking is encountered, the welding techniques mentioned under the A solidification mode will generally cure the problem.

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Examples of stainless steels and their corresponding weld metals that solidify in F mode include duplex, lean duplex, and super duplex stainless steels such as 2205 base metal and its 22 9 3-N L (2209) filler metal; 2101 and its normal filler metal 23 7-N L (2307); and 2507 and its corresponding filler metal 25 9 4-N L (2594). Other base metals and filler metals that solidify as F mode include 29 9 (312), 17 (430) and 18-L Nb. Any austenite found in these steels and weld metals at ambient temperatures results from solid state phase transformation of some ferrite to austenite, as discussed in [Clause 4.3.4.3](#). Steels and weld metals such as 17 (430) and 18-L Nb are outside of the scope of this document, but 29 9 (312) is within the scope.

#### 4.2.6 Mixed solidification modes

When a weld metal composition is very close to one of the boundaries between solidification modes, mixed solidification modes ~~could~~ occur. These ~~could~~ be A/AF, AF/FA, or FA/F. From the point of view of resistance to solidification cracking, it makes little difference if the solidification modes are mixed A/AF (similar likelihood of solidification cracking) or if the solidification modes are mixed FA/F (similar solidification cracking resistance). But mixed AF/FA solidification can be significant because AF mode has a significantly greater tendency for solidification cracking than FA mode. Mixed mode solidification can happen on a microscopic scale or on a macroscopic scale. ~~Figure 1~~ [Figure 1](#) shows a submerged arc single run fillet weld exhibiting macroscopic mixed solidification mode, with solidification cracking in the AF solidification mode region.

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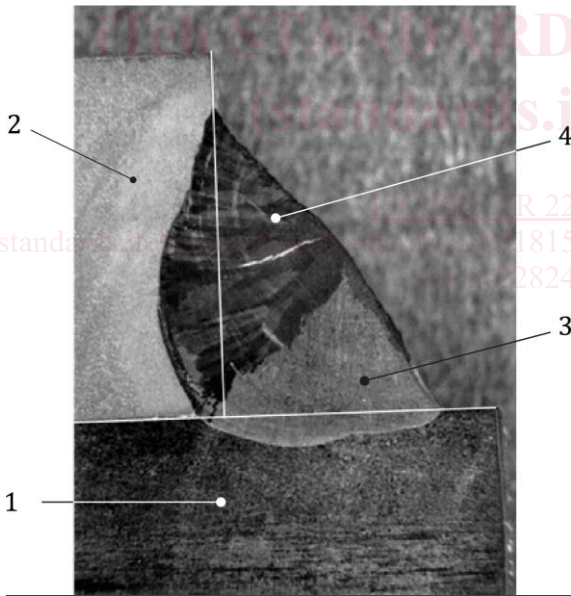
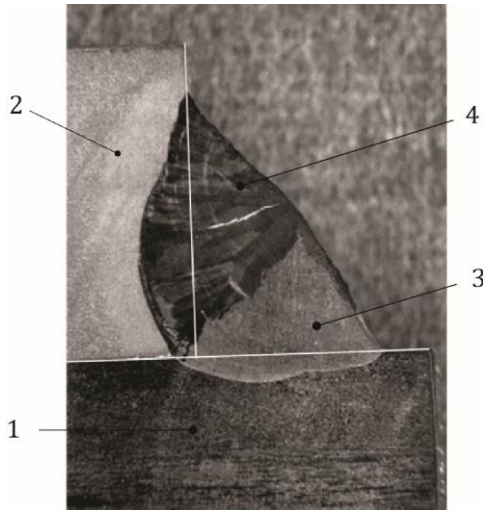
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**Key**

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|-------------------------|---------------------------------------|
| 1 stainless steel plate | 3 FA solidification mode area of weld |
| 2 carbon steel plate    | 4 AF solidification mode area of weld |

NOTE: — the — The difference in etching – the region of the weld close to the 304 stainless steel solidified in FA mode, while that close to the structural carbon steel solidified in AF mode. Scribe lines indicate the original metal surfaces before welding. The 304 stainless steel helped to promote FA solidification, while the structural carbon steel helped to promote AF solidification. A solidification crack can be seen in the AF solidification mode region.

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