

NEW WELDING PROCEDURES FOR REPAIRING H13 AND P20 TOOL STEELS

B. Silva^{1,2}, I. Pires^{1,2*}, L. Quintino^{1,2}, R. Miranda^{2,3}

¹ IST-UTL Instituto Superior Técnico, Av. Rovisco Pais, 1200 Lisboa, Portugal

² IDMEC, Instituto de Engenharia Mecânica, Av. Rovisco Pais, 1200 Lisboa, Portugal

³ FCT-UNL, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Quinta da Torre, 2829-516 Monte da Caparica, Portugal

**Email: ipires@ist.utl.pt*

ABSTRACT

AISI H13 and P20 are tool steels commonly used in the manufacturing of polymer injection moulds. P20 is provided by manufactures in the quenched and tempered condition while H13 steel can be used both, in the annealed condition and quenched and tempered state.

Welding technologies are frequently applied to repair polymer injection moulds, namely due to changes in design and alterations due to use.

The application of welding technology in plastic injection mould repair is not simple due to the mould material itself (high alloy steels), to the complex shapes with reduced thicknesses, small tolerances, and hard-to-reach-areas. Welding tool steels moulds is also extremely demanding regarding the mechanical/metallurgical know how and the welder's skills.

The aim of the present paper is to investigate TIG welding in this particular application, the metallurgical behaviour of AISI P20 and H13 tool steels during welding thermal cycles, and to define welding procedures to repair these tool steels.

1. INTRODUCTION

Polymer injection moulds frequently require some form of repair by welding: (a) during the manufacture, by errors in machining or by some change in the design of the part to be injected and (b) during the service, by the incidence of failures in the mould [1]. Fusion welding is frequently used to repair worn or cracked surfaces and to modify the shape of existing tools [2]. However, the application of this repair technology is not simple due to complex shapes, hard-to-reach areas, thin blades and small sizes within specified tolerances. Welding in moulds is extremely demanding in what regards the mechanical/metallurgical know how and the welder's skills. Mould materials are, generally, high alloy steels and the weld deposits must be done in complex geometries, with reduced thicknesses and small tolerances, and access is often difficult [3].

Despite the fact that equipments and filler materials for tool steels welding are available in the market, there is a lack of know-how relatively to the weldability and welding procedures of tool steels (the scientific work published for sheet welding does not contemplate moulds specific requirements) [4].

The required quality of the weld is not only related to the suitable mechanical properties, but also to the weld and the heat affected zone (HAZ) behaviour when finishing processes are applied to provide a uniform and adequate texture to the mould cavity [6].

The correct use of welding technologies in mould repair can help mould makers to obtain high quality welds and will allow them to implement and spread their use, facilitating re-utilization of the mould with the related cost savings.

The purpose of the present study is to analyze the influence of welding parameters on the metallurgical behaviour of AISI P20 and H13 tool steels, as well as welding procedures for mould repair.

2. EXPERIMENTAL PROCEDURE

Welds were made with TIG welding process in two base materials (AISI P20 and H13 tool steel). These tool steels are commonly used in the manufacturing of polymer injection moulds. P20 steel was provided in the quenched and tempered condition, with hardness between 30 and 34 HRC, and H13 steel was tested in, both annealed and quenched and tempered states, (with the latest having an hardness between 50 and 52 HRC). The welds were made using a filler wire recommended by the steel manufactures. The composition of the base metals and the filer wires are indicated in table 1.

Table 1. – Chemical composition of base metal and filer wires.

	C	Mn	Cr	Mo	V	Si	W	Cu	Ceq
P20 base metal	0.4	1.5	1.9	0.2	-	-	-	-	1.07
H13 base metal	0.4	-	5.3	1.4	1.0	1.0	-	-	1.94
P20 filer wire (ø 1mm)	0.09	0.95	1.15	0.47	-	0.62	-	0.15	0.58
H13 filer wire (ø 1mm)	0.32	0.29	2.25	-	0.54	0.29	4.12	-	0.93

TIG welding is characterised as a low heat input processes that lead to good quality welds.

Beads on plate were made on 24mm thick steel, using four levels of welding current and two welding speeds, as indicated in table 2. Two preheating temperatures were used (250°C and 350°C, for 2 hours) and in some trials no pre-heat was done, to account for its influence on the hardness of the weld after welding. The wire feed speed was adjusted in each case to produce satisfactory welds.

Table 2. – TIG welding parameters (arc voltage=11V)

<i>Current</i> [A]	<i>Welding speed</i> [cm/min]	<i>Heat Input</i> [KJ/Cm]
90	15	1.98
100	15	2,20
110	15	2.42
120	15	2.64
90	7	4.24
100	7	4.71
110	7	5.81
120	7	5.65

Figure 1 shows the sequence of bead on pates adopted in this study.

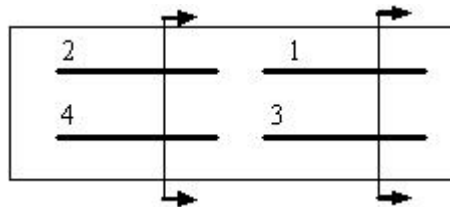


Figure 1– Illustration of the single welds welding procedure

Multipass welds were also made with the purpose of investigating the effects of repeated welding thermal cycles in the hardness and microstructure of the welds, using two levels of welding current, 90, and 120A, and two welding speeds, 7 and 15cm/min, as shown in figure 2.

After welding, some samples were subjected to a tempering post-heat treatment to evaluate the possibility to obtain hardness values in the heat affected zone (HAZ) and weld metal (WM) similar to base metal (BM).



Figure 2 – Illustration of Multipass welding

After welding the plates were sectioned and samples were prepared for metallographic analysis by grinding, polishing and etching (Nital 2% was used as the etching agent). Hardness profiles in the different regions of the welds were measured using a Vickers microhardness tester with a load of 1 Kgf in selected points as shown in fig 3.



Figure 3 - Illustration of the hardness measurements.

3. RESULTS AND DISCUSSION

TIG weld deposits made with H13 and P20 tool steels show good superficial homogeneity, without detectable superficial defects, as shown in fig 4. The weld dimensions of TIG deposits width varied between 3.3mm and 6.3mm, while the depth varied between 0.8 mm and 1.9mm, being the higher values associated to higher heat inputs.

After etching the samples, it was observed that the heated affected zone was smaller than 1.8 mm.



Figure 4 - TIG weld deposits.

Relatively to the microstructure, differences were observed between P20 and H13 tool steels, so results will be presented separately.

P20 steel

Microstructural observations and hardness evolution of the samples show that for single weld TIG deposits the Base Metal (BM) has a tempered martensite microstructure, the weld metal (WM) and the Heated affected zone (HAZ) are constituted by martensite with high hardness levels, as shown in fig 5.

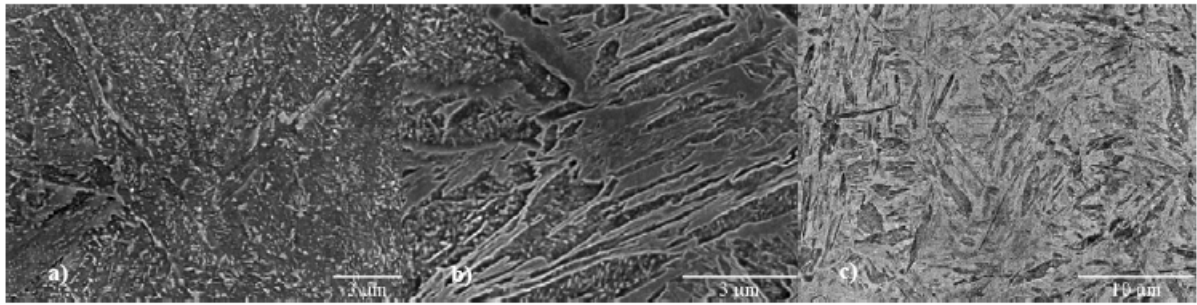


Figure 5 - SEM photomicrography of a P20 TIG Weld, showing: a) Base metal, b) Weld metal and c) heated affected zone.

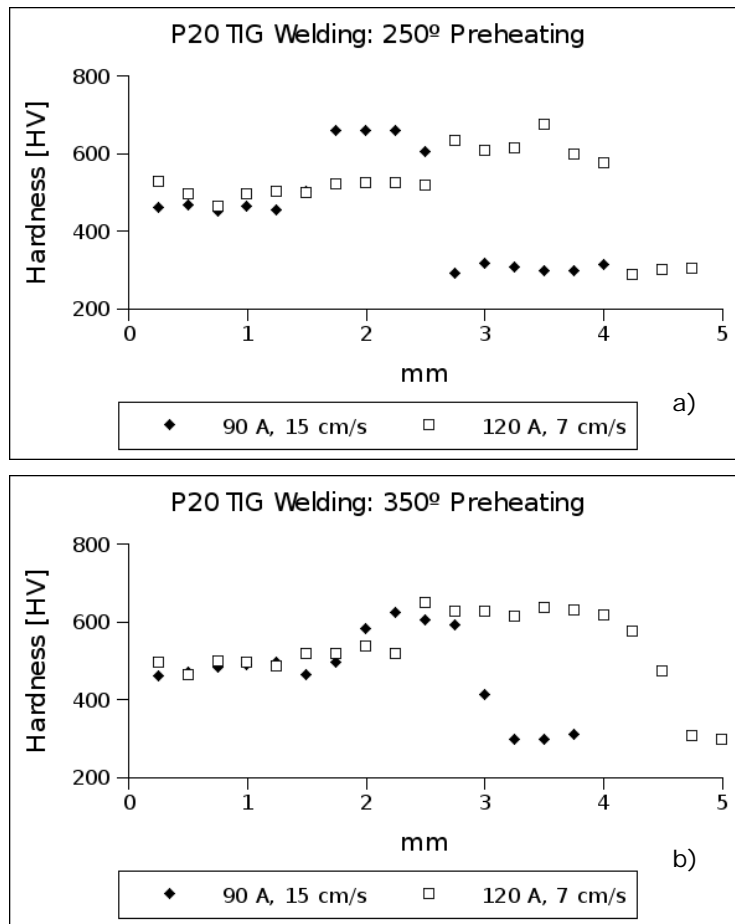


Figure 6 - Mean hardness of TIG single pass welds, for different welding conditions a) with a 250°C preheating temperature; b) with a 350°C preheating temperature

The higher values of hardness in the heated affected zone, close to the fusion line, are due to the thermal modification in that region, which consisted of the re-austenitisation of the steel, as well as dissolution of Cr-rich carbides due to the high peak temperature reached followed by martensite formation on rapid cooling [7].

The weld metal has, however, lower hardness, when compared with the heated affected zone, due to the higher dilution effect and to the lower hardness of the filler metal and the possibly of the presence of retained austenite.

In figure 6 it can also be seen that within the range of parameters used, hardness values are relatively independent of the heat input, and that the variation of preheating temperature does not promote, also, significant changes in the hardness profile.

Figure 7 illustrates the hardness profiles, measured in a horizontal line parallel to the surface, in multipass welds, at one millimeter from the surface. It is observed that the average hardness values measured in the weld metal multipass samples were significantly lower than those of the single pass deposit, due to the tempering of the martensite by subsequent stress relieve effects.

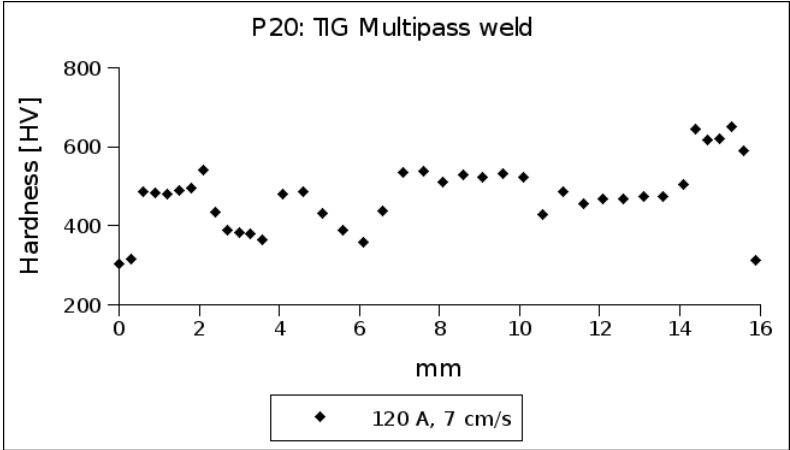


Figure 7 - Hardness profile multi pass TIG welds, measured in a horizontal line parallel to the surface, at 1mm from the surface.

However, it is worth to mention that in order to produce a uniform hardness profile it is necessary to make a post-weld heat treatment, as these results indicate that the effect of multipass welding is not sufficient to lower the harness to values correspondent to the hardness of the base metal (300 HV). For the welds which were post-weld heat treated (tempered), it was possible to obtain a mean hardness of 300 HV in both weld metal and heated affected zone, as observed in fig. 8.

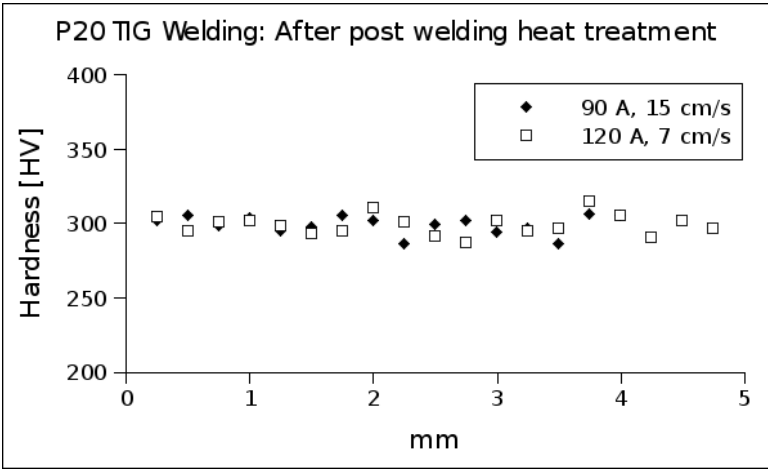


Figure 8 - Hardness profile of single, P20 TIG welds after post-weld heat treatment.

H13 steel

In H13 tool steel similar results were observed, indicating the presence of martensite in the heated affected zone and weld metal. However, as far as H13 is concerned the hardness profile shows a region in the heated affected zone, with lower hardness comparatively to the base metal, as shown in fig. 9. This is the result of an over-tempering effect. Unlike P20 tool steel, where cracking can arise in regions of high hardness in the heated affected zone, that could be reduced to values equal to the base metal by a tempering treatment after welding, for H13 tool steel the only way to reduced the hardness is through a complete post-heat treatment of quenching and temper.

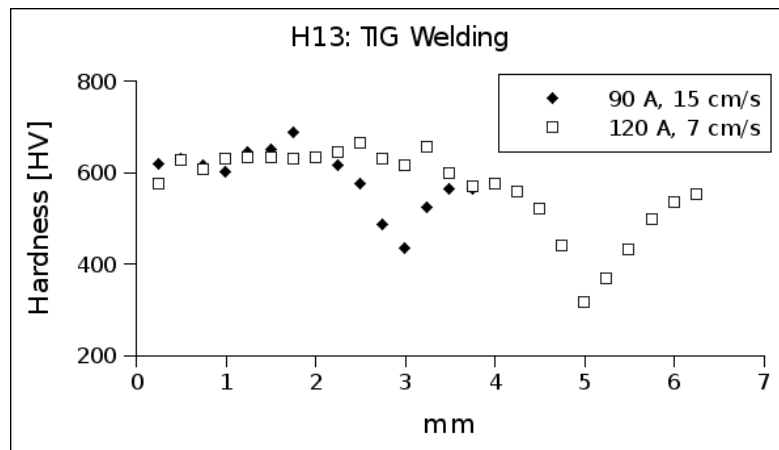


Figure 9 - Mean hardness of H13 TIG single pass welds, for two welding conditions.

In order to explain the regions of lower hardness in the heated affected zone of the H13 tool steel, the tempering diagrams from the steels manufactures, as shown in fig. 10, were used. After the quenching and tempering treatment, H13 tool steel presents a range of hardness between 50 and 52 HRC (base metal hardness), which, according to the diagram indicates a tempering at around 550-600°C. Therefore, material regions that during welding reach a temperature higher than the above mentioned and lower than the austenitization temperature, will suffer an over-tempering, with an inherent decrease in hardness.

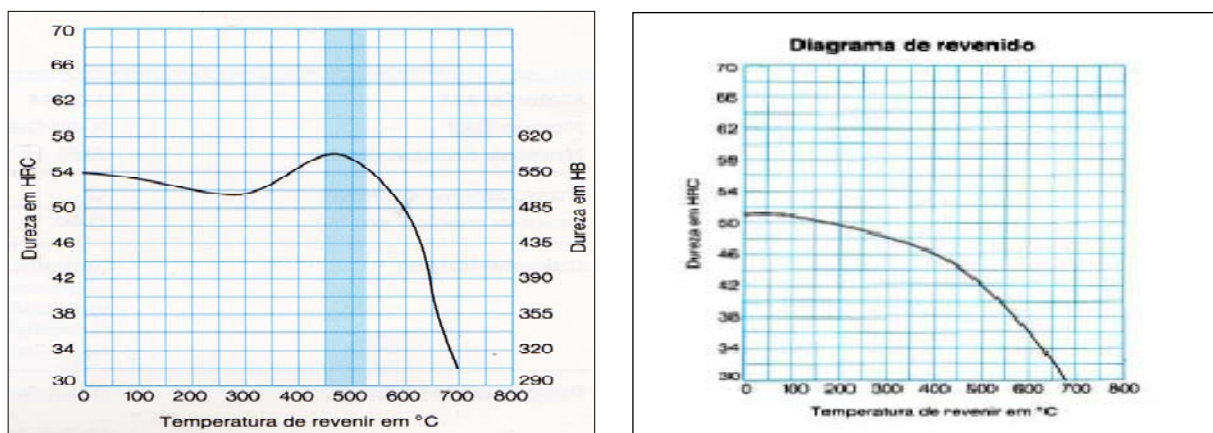


Figure 10 - Tempering diagrams a) H13; b) P20 [8]

Relatively to the multipass welds, similar results were obtained, where the tempering effects give rise to areas with lower hardness comparatively to the base metal, which can affect the structural integrity of the mould, as illustrated in fig 11.

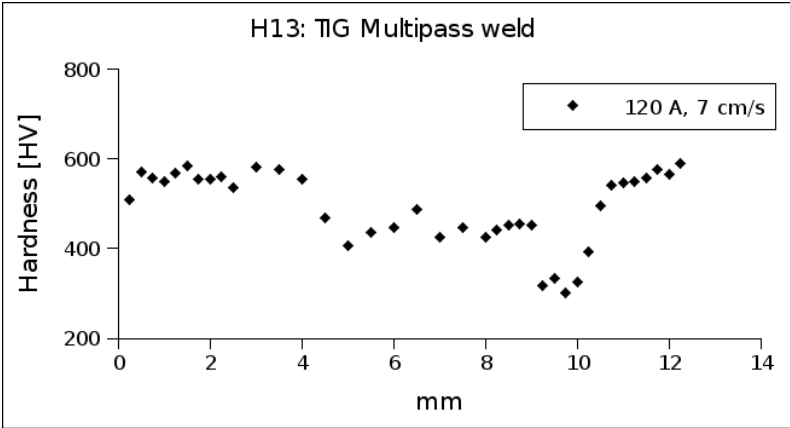


Figure 11 - Mean hardness of H13 TIG multipass welds, made with a 350°C preheating.

Figure 12 represents the evolution of hardness for TIG welds made with no pre-heating and with a 350°C preheating. It can be seen that pre heating has little influence on the hardness profile, being the average hardness slightly lower for the samples that were pre-heated. However, preheating has a beneficial effect in service lifetime since it reduces residual stresses and prevents cracking in service.

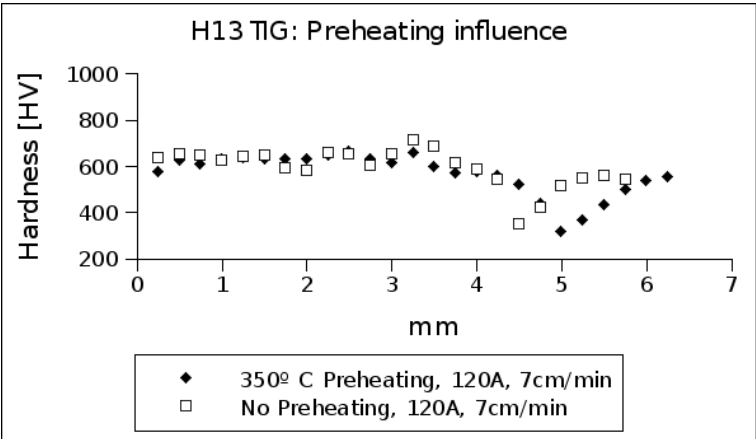


Figure 12 - Mean hardness of H13 TIG single pass welds, with no pre heating and 350°C preheating, for 120A and 7cm/min

Some welding trials were also made in the annealed conditions followed by a quenched and tempered treatment. From the results obtained it can be observed from fig 13, a uniform hardness distribution along the weld metal, heated affected zone and base metal, with a value similar to the base metal. This result indicates that when welding the H13 steel in the annealed state it is possible to obtain after quenching and tempering a similar structure to the base metal. Despite the composition of the filler material being slightly different, its behaviour to heat treatments was similar.

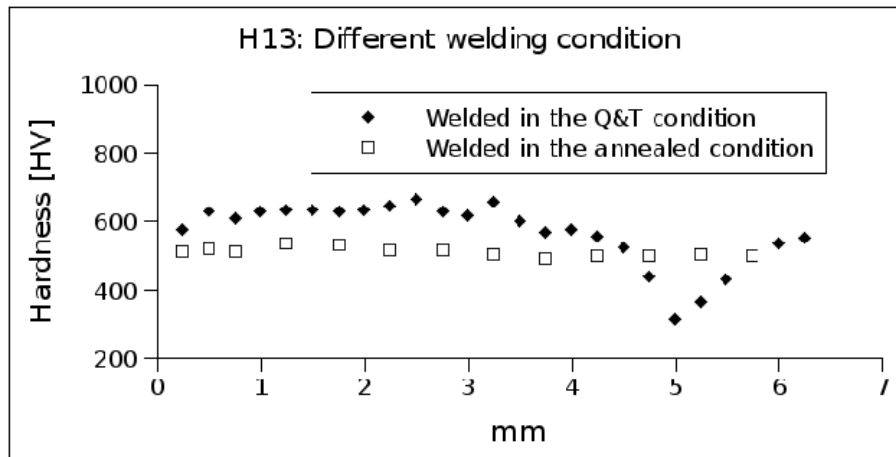


Figure 13 - Mean hardness of TIG single pass welds, made in the annealed condition, which were than quenched and tempered and welds made in the quenched and tempered state.

4. CONCLUSIONS

Based on the experimental investigation, the following conclusions can be drawn:

a) P20 tool steel:

- The welds present regions with high hardness values compared to the base metal, corresponding to martensitic microstructures. These occur using or not pre-heating. However, in order to avoid risk of material cracking during welding, preheating can be done. In multipass welds, overlapped regions were tempered by repeated welding thermal cycles, lowering the hardness values. However, this procedure did not lower the hardness to base metal values.

- The post tempering treatment made in some welded samples has shown that it was possible, with a post-welding heat treatment, to obtain a uniform hardness profile across the weld, even in case of using a filler wire with a composition different from that of the base metal.

b) H13 tool steels:

- The results were similar to the P20 tool steel, indicating the presence of martensite in the heated affected zone and the weld metal. However the heat affected zone has a lower hardness comparatively to the base metal, due to an over-tempering effect.

- Opposite to P20 tool steel, where a uniform hardness in weld can be obtained by a tempering treatment after welding. For the H13 tool steel a complete post-heat treatment of quenching and tempering is required.

Based on these results the following procedures should be used in order to obtain good quality welds:

- Before welding, the material should be pre-heated, to avoid risk of failure. A pre-heat temperature of 250°C, during 2 hours, is sufficient to prevent thermal shock without altering material structure.

- During welding the heat-input should be adjusted to the dimensions of the zone to repair. For bigger areas to repair, higher heat inputs should be used, in order to increase deposition rate.
- After welding a post tempering treatment should be done using a temperature between 600-650°C for a period of time of 2 hours.

Mould welding repair, if properly done, leads to good mould properties and improved performance. Plastic injection moulding companies and mould makers need to use correct moulding procedures to achieve good results and increase the reliability of the mould, leading to costs savings.

5. ACKNOWLEDGEMENTS

This work was supported by the POCI 2004/FCT/Portugal.

6. REFERENCES

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