The role of addition of Ni on the microstructure and mechanical behaviour of C-Mn weld metals

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The aim in this work is to study the influence of nickel content (as-welded state and after stress relief heat treatment) on the microstructure and toughness of CMn weld metals obtained with submerged arc welding. The nickel content vary between 0.50 wt.% and 3.11 wt.%. The microstructures were observed using optical microscopy (OM) and scanning electron microscopy (SEM). The toughness was evaluated by Charpy-V impact testing in samples cut transversally to the weld bead. The impact energy showed that nickel content up to 1 wt.% improves the toughness due to the increase of the acicular ferrite (AF) content and microstructural refinement. On the other hand, higher nickel contents have a deleterious effect on the toughness due to the presence of the microconstituent martensite-austenite (M-A) in the weld metal. The stress relief heat treatment did not improve too much the weld metal toughness, even the M-A suffering decomposition (ferrite+carbide). This may be explained by the precipitation of carbides along the boundaries of the ferrite.

Key words: Microconstituent martensite-austenite (M-A). Nickel effect. Submerged arc welding. Weld metal.

1 Introduction

Although nickel is recognized to be beneficial to the toughness of C-Mn and low-alloy steel weld metals (FARRAR; HARRISON, 1987), there is not much literature reporting in details the mechanisms responsible for its effect. There is no publicized consensus, for example, about which nickel content range is optimum in order to obtain the highest mechanical properties of the weld metals.

Generally, weld metal of CMn steel with a microstructure formed predominantly by acicular ferrite (AF) has high mechanical properties for both notch toughness and strength. Enhancements in the mechanical properties is mainly due to the very fine grain size of the acicular ferrite (1µm to 3µm), as well as its high boundary angle and high dislocation density, which reduces crack propagation. However, the predominance of acicular ferrite in the microstructure is not the only factor determining the high toughness of the weld metals. Many authors (GRONG, 1992; EVANS, 1991; ALÉ; REBELLO; CHARLIE, 1996; MATSUDA et al. 1996; HIRAI, 1981) have reported that microphases, specifically the martensite-austenite constituent (M-A) can influence strongly the toughness of weld metals of CMn, low-alloy and medium-alloy steels.

The aim in this study is to investigate the influence of nickel content on the impact toughness of CMnNi weld metals. The welding process used was the submerged arc welding. In order to avoid re-heated regions, the weld joints were composed of a single bead. The welded joints were analysed in the as-welded condition and after an industrially practised stress relief heat treatment.

2 Experimental details

Plates of the ASTM A36 steel were used as base-metal. The dimensions of the plates were 500 x 100 x 19mm. Wire containing low C and middle Mn content was used in combination with a flux, corresponding to the F7A2-EM-12K, American Welding Society (ASW). The change of the Ni content in the weld metals was achieved by controlling the addition of Ni powder in the weld beads. The submerged arc welding process allowed changing the nickel content of the weld metals without the necessity to manufacture wires with different chemical compositions. Table 1 shows the chemical composition of the base metal as well as the addition metal.

Table 1: Chemical composition (in wt.%) of the base metal and wire used

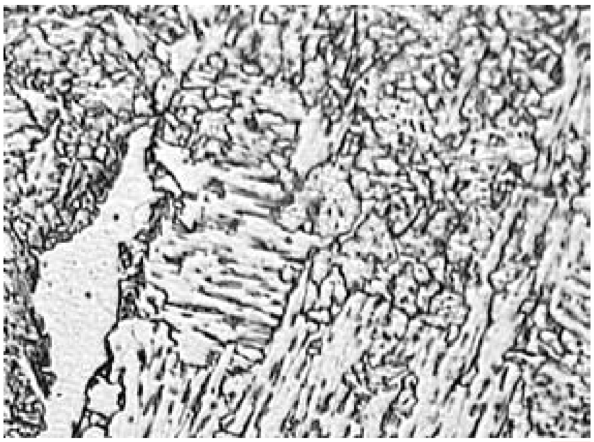
	C	Mn	Si	S	P
base-metal	0.130	0.780	0.300	0.017	0.020
wire	0.130	1.300	0.320	0.019	0.021

Source: The authors.

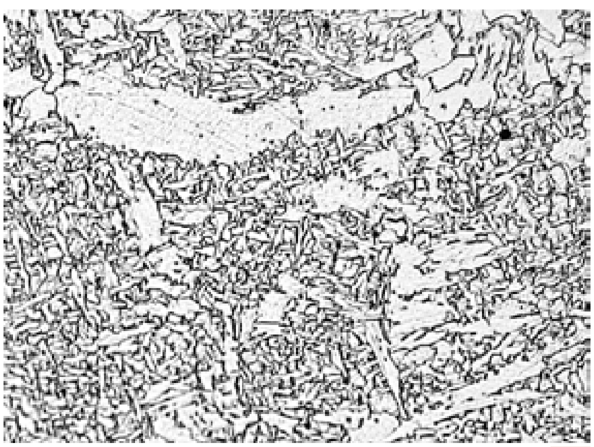
After welding, the specimens for Charpy-V tests were cut from the columnar region of the weld metals. Specimens were heat treated at 600°C for two hours in order to relieve stresses generated during the welding process. The quantitative evaluation of the microstructural constituents in the as-welded condition and after heat treatment was done using optical and electron scanning microscopy. The analysed constituents are those designed by the IIW/IIS: acicular ferrite (AF), polygonal ferrite along grain boundaries (PF(G)), polygonal ferrite in the interior of the grain (PF(I)), second phase aligned ferrite (FS) and martensite-austenite constituent (M-A).

3 Results and discussions

Increasing Ni content in the weld-metals lead to a refinement of its microstructure, as shown in Figure 1. That means that more acicular ferrite is formed when Ni is added in the weld metal. The effect of Ni on the acceleration of the formation of the constituents AF in the weld-metals is contrary to that observed for the elements such as Mo and Cr, as considered by Trindade et al. (2004).



(a)



(b)

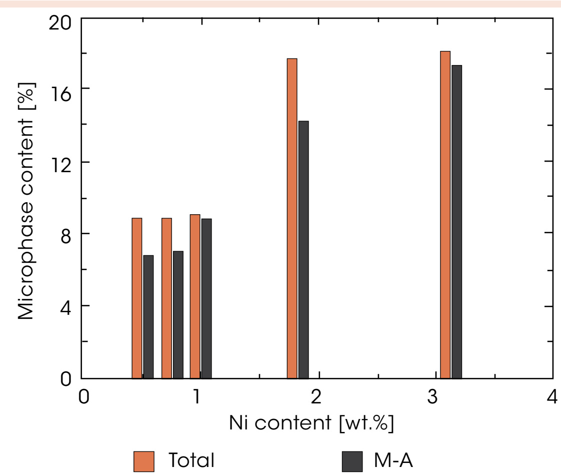
Figure 1: Optical micrograph of weld metals: (a) without Ni addition and (b) with 1.83wt.% of Ni.
Source: The authors.

Table 2 shows the mean values of the measured constituents present in the weld metals. The amount of the constituents did not change much from the as-welded state compared with that after heat treatment for the same Ni content. However, a continuous increase in AF content and a decrease in PF(G), and the FC content are evident as the Ni increases.

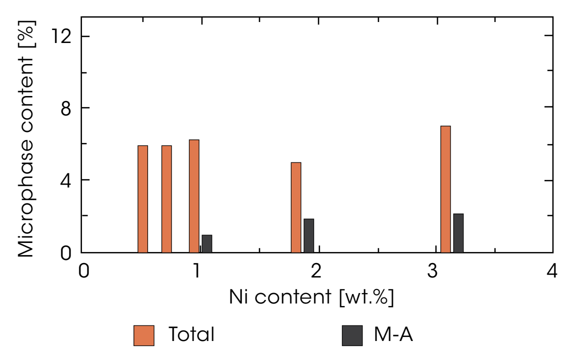
% Ni	as-welded					after stress relief heat treatment				
	AF	PF(G)	PF(I)	FS	FC	AF	PF(G)	PF(I)	FS	FC
0.50	52	32	4	11	1	50	33	8	6	3
0.72	57	31	1	10	1	56	32	5	5	2
0.97	59	26	3	12	0	58	28	8	5	1
1.83	62	22	4	12	0	59	24	9	7	1
3.11	65	17	4	14	0	63	20	9	8	0

Table 2: Microstructural constituents presented in the weld metals, in the as-welded and after heat treatment conditions.
Source: The authors.

It is important to note that the PF(I) in weld metal after heat treatment is double to that of the weld metal in the as-welded state. This is due to the fact that during heat treatment there was a considerable coarsening of the AF, which becomes the shape of the PF(I). The increasing of FC after



(a)



(b)

Figure 2: Microphases present in weld metals, (a) as-welded condition and (b) after stress relief heat treatment.
Source: The authors.

heat treatment could be explained by the decomposition of the constituent FS into ferrite+carbides (Figures 3a and 3b).

Figure 2 shows that the weld metals, after heat treatment, have a low or non-existent amount of the microconstituent M-A. This confirms a decomposition of the microconstituent M-A during the heat treatment (Figure 3b).

Figure 4 presents the Charpy-V energy of the weld metals in both as-welded and after heat treatment for stress relief conditions. It can be seen that a weld metal containing 0.97 wt.% of nickel exhibits the highest toughness for almost all test temperatures in both of the as-welded (Figure 4a) and after stress relief heat treatment (Figure 4b).

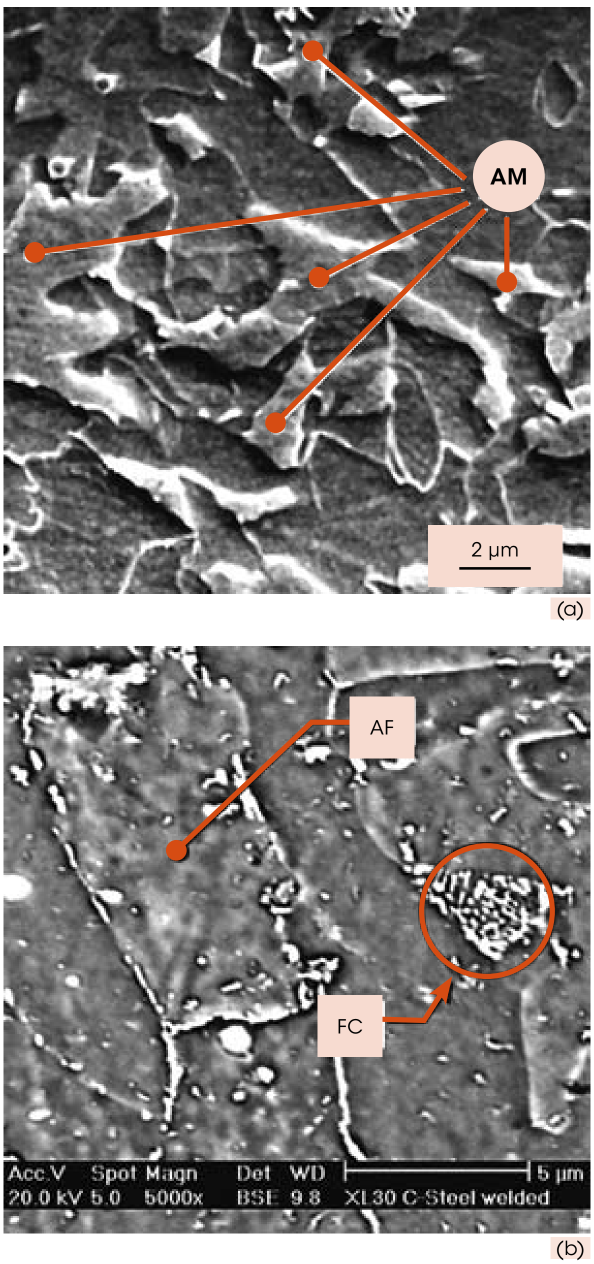


Figure 3: Scanning electron micrographs, (a) constituent M-A in the as-welded state and (b) ferrite-carbide (FC) after heat treatment.
Source: The authors.

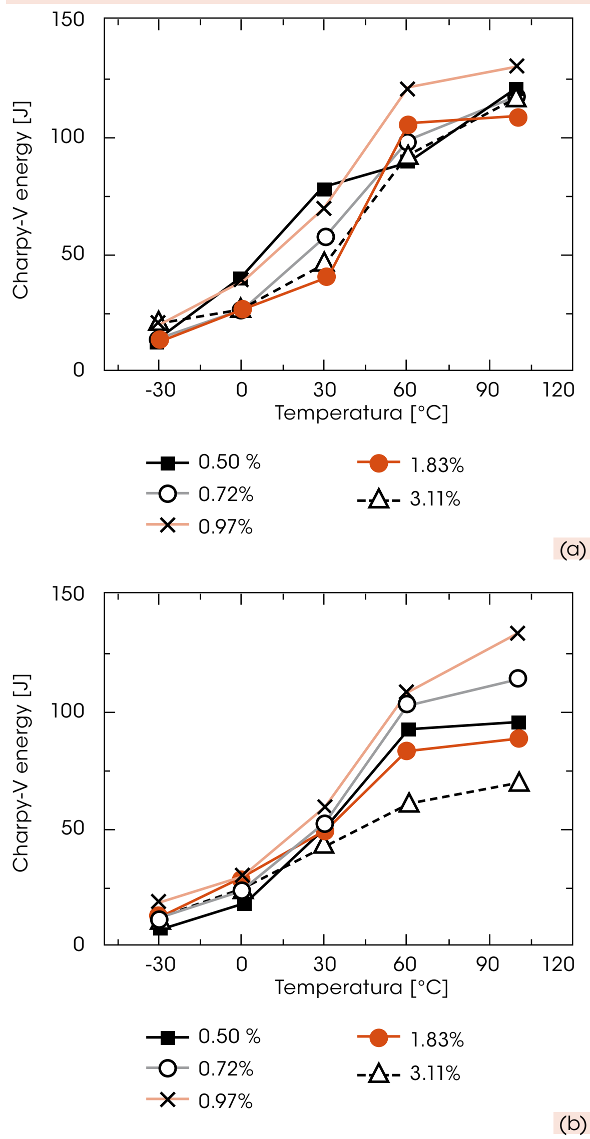


Figure 4: Impact Charpy-V energy at different test temperatures, (a) in as-welded condition and (b) after stress relief heat treatment.
Source: The authors.

Figure 5 shows that the lowest temperatures during impact tests corresponding to the Charpy-V energies of 30J, 50J and 70J were obtained by the weld metal containing 0.97 wt.% of nickel.

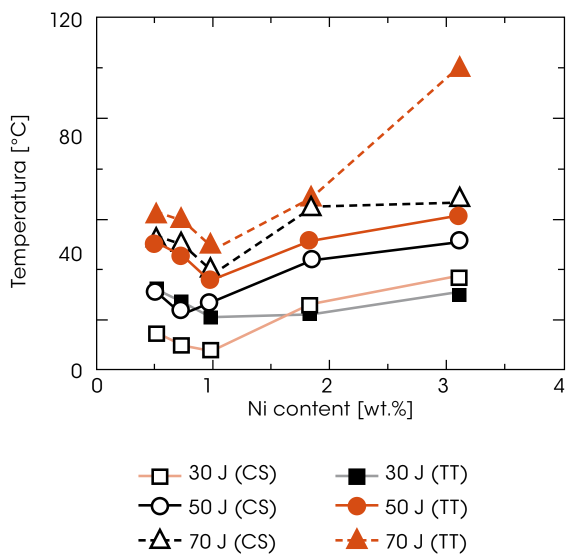


Figure 5: Impact test temperature in which the absorbed energies of 30J, 50J and 70J were plotted as function of the nickel content in the weld metals.
Source: The authors.

Figure 5 shows that the heat treatment almost did not affect the toughness of the weld metals. However, for the nickel contents of 1.83 wt.% and 3.11 wt.%, it can be observed a considerable reduction in the impact energy test for temperatures higher than 30 °C for those weld metals submitted to heat treatment. The influence of nickel on the microstructure of the weld metal is similar to that of manganese, as observed by Evans (1995) and HIRAI (1981). Optical microscopy analysis did not explain all results concerning the behaviour of the weld metal during the impact Charpy-V tests. The nickel caused an increase in AF as well as a refinement of the microstructure of the weld metals. Consequently, an increase in toughness was expected with the increase in nickel content, but this was not the case, as shown in Figures 4 and 5. With help of the scanning electron microscopy, a gradual increase in the microphases was observed (see Figure 2) as the nickel content increased. This phenomenon is generalised by stating that when the amount of microconstituent M-A reaches approximately 7%, the increase in AF is insufficient to compensate the deleterious effect of the microconstituent M-A during the impact Charpy-V test.

The effect stress relief heat treatment on the toughness of the weld metal for the lowest (-30 °C) and highest (100 °C) tested temperatures resulted as a function of the nickel content. It was carefully analysed. The Charpy-V energy at low temperature is strongly affected by an increase in AF content. Since the stress relief heat treatment did not change the constituent amounts of the weld metal, it is reasonable to expect that there is no difference in the behaviour of weld metals during the Charpy-V tests at low temperature before and after heat treatment. On the other hand, it would be expected that the carbide precipitation along the grain boundaries of the ferrite would lead to the brittle fracture for highest test temperature during the impact Charpy-V test. Yet, this effect was not observed.

The Vickers hardness (5 kg) increased progressively with the nickel content in both conditions (Figure 6), mainly due to the hardening effect caused by solid solution and microstructural refinement. Figure 6 also points out a clear reduction in hardness due to the stress relief heat treatment. A similar effect is find in literature (TRINDADE et al., 2004; EVANS, 1991) in weld metal containing 1.4 wt.%Mn plus Ni. Higher hardening values were observed due to the strong effect of Mn hardening the weld metals by solid solution.

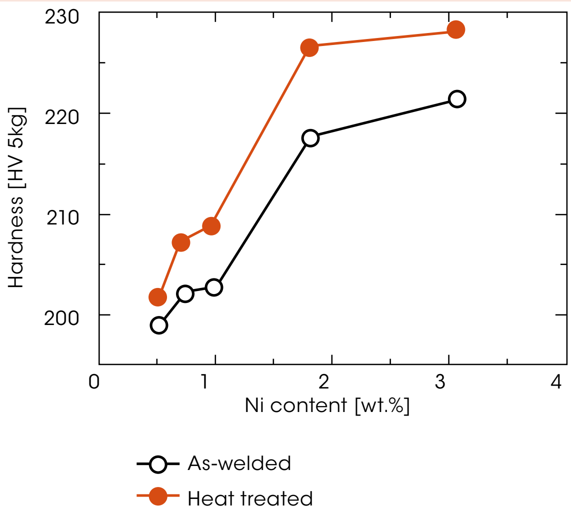


Figure 6: Vickers hardness (5kg) as a function of the nickel content in the weld metals
Source: The authors.

It was observed by Trindade et al. (2006) and Souza (1996) that the optimum inclusion diameter for acicular ferrite is about 0.3 μm. It can be observed in Figure 7 that the amount of inclusions with diameter close to 0.3 μm increases as the nickel content increases. This helps to explain the increasing amount of AF as the nickel in the weld metals is increased.

4 Conclusions

From this work, it was possible to conclude that the optimum Ni content in the weld metal is around 1wt.%, because this value enables the highest Charpy-V energy of the weld metals for almost all tested temperatures. This is basically due to the high amount of acicular ferrite and the low amount of the M-A constituent in the weld metal. For Ni higher than 1wt.% there was decomposition of the microconstituent M-A into ferrite-carbide along grain boundaries of the acicular ferrite, which did not allow a better performance of the weld metals regarding to the toughness after heat treatment for stress relief.

Acknowledgements

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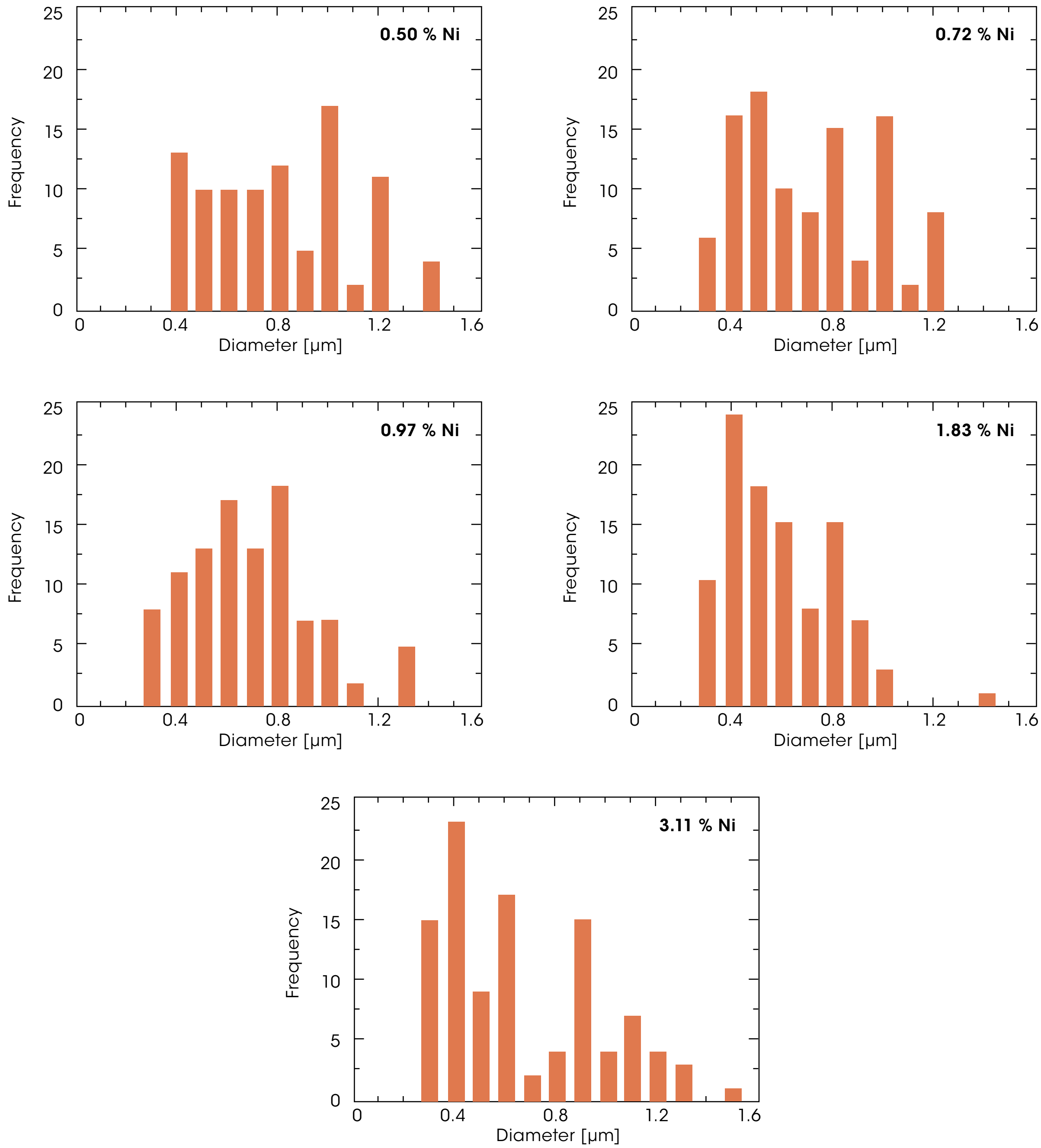

Figure 7: Distribution of the non-metallic inclusion diameters in weld metals of CMnNi steels.
Source: The authors.

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