



FEATURES OF MELTING, STRUCTURE AND PROPERTIES OF Ni–Mn–Cu SYSTEM NICKEL ALLOYS

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Influence of nickel alloy composition and method of melting on their structure and properties were studied. Melting was performed in argon and under a layer of flux. It is established that argon-arc melting of nickel alloys with high manganese content allows producing ingots of a more stable composition than in submerged-arc melting. It is noted that alloys of the considered system are prone to porosity. Increase of pouring temperature promotes reduction of porosity in ingots. Structure of ingots with different manganese content in as-cast condition, after annealing and rolling was studied. It was shown that at manganese content in the alloys of up to 25 wt.%, it is possible to produce ingots of a higher strength and ductility, which lend themselves easily to forming. After rolling the alloys have the structure of fine-grained solid solution. Strength of such a metal reaches 900–950 MPa at relative elongation of about 40 %. At greater manganese content the alloys become brittle as a result of formation of intermetallic phases in them. 8 Ref., 3 Tables, 7 Figures.

Keywords: *Ni–Mn–Cu system alloys, submerged-arc and inert-gas arc melting, structure, mechanical properties of alloys, brazing, braze alloy*

It is known that Fe-based structural materials usually have the structure of a solid solution, while braze alloys in their majority are eutectics, often having brittle phases in their composition. This contradiction is eliminated due to brazed joint design, brazing modes or some special techniques. Therefore, development of braze alloys based on solid solutions has been an urgent task for a number of years.

Ni–Mn–Cu system alloys have been quite well studied in many works [1–4]. Analysis of phase composition of this system alloys shows [1] that it has broad areas of alloys with solid solution structure with acceptable melting temperature for brazing corrosion-resistant steels. These are, mainly, Cu-based alloys. This system is the base for such well-known braze alloys as VPR-2, VPR-4, PM38ML, PM-17, P65, etc. [5, 6]. Nickel alloys of this system are not in such a good situation. Among widely accepted braze alloys we can mention US braze alloy BNi-8, but it is eutectic with 7 wt.% Si. In works [7, 8] alloys of this system were studied in the field of concentrations, wt.-%: 7–27Mn, 7–27Cu, 1–10Si, Ni being the rest, in order to determine the possibility of producing eutectic alloys with a lower content of silicon. The most interesting results were obtained when studying alloys of Ni–24Mn–Cu–Si system.

Nonetheless, development of a braze alloy with solid solution structure is an attractive prospect, but it is very difficult to implement. The purpose of this work was to study the structure and properties of nickel alloys of Ni–Mn–Cu system, depending on composition and melting technology.

Analysis of the constructed respective constitutional diagram (Figure 1) shows that the regions of NiMn and Ni₃Mn intermetallic phases have an extension in the three-component system up to a certain copper content. We have studied the structure and properties of the alloys, located in the near-boundary region (see Figure 1; Table 1). As is seen from the Table and presented diagrams, moving along the abscissa of 19 wt.% Cu, we must go over from alloys with solid solution structure to a structure with intermetallic compounds.

Melts were performed under a layer of cryolite. The alloy was poured into a cast iron mould, and then the possibility of ingot rolling was tried out and the microstructure was studied.

Microstructure of ingot 8 with low manganese content (20 wt.%) is single-phase in the cast and annealed conditions (Figure 2, *a, b*). Intercrystalline boundaries are clean. With manganese increase up to 25 wt.% (ingot 9), an eutectic component precipitates in interdendritic regions in the ingot center, and the structure becomes two-phase (Figure 2, *c*). However, annealing at 950 °C restores the single-phase structure through the entire ingot volume (Figure 2, *d*). The alloys can be rolled down to a rod with 14 mm side.

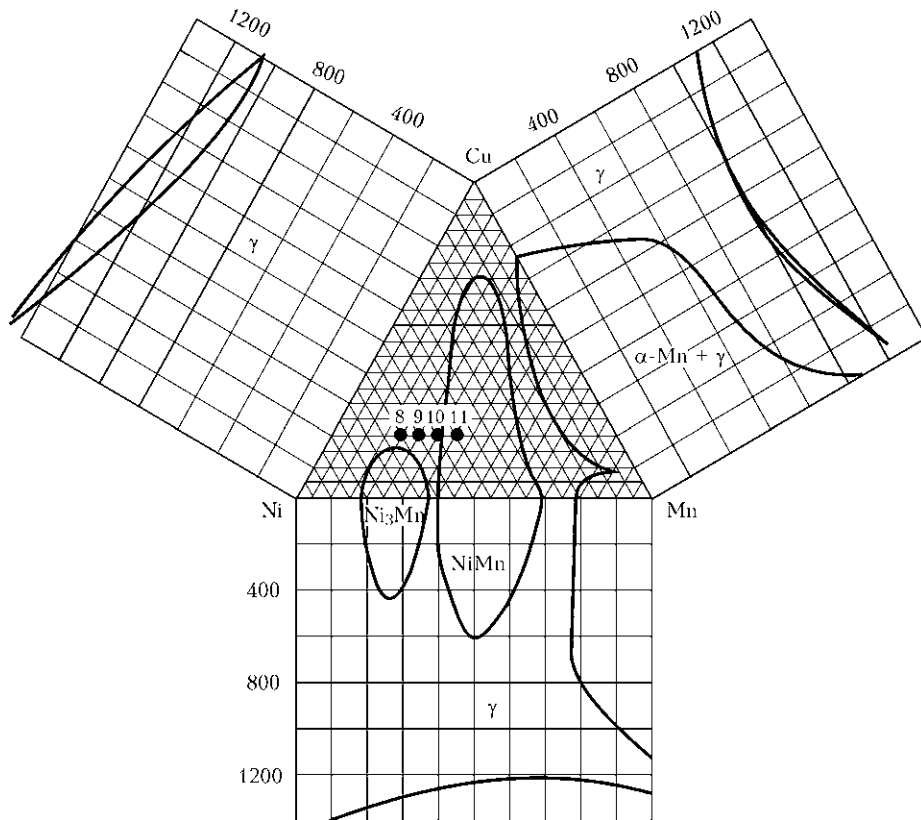


Figure 1. Phase areas in alloys of Ni–Mn–Cu system, compared to phase areas in binary systems [1]: 8–11 – number of ingot acc. to Table 1

Table 1. Composition and structure of the studied alloys

Ingot number	Composition, wt.%					Ingot weight, kg	Second phase quantity, %	Porosity, %
	Ni	Mn	Cu	Si	Ce			
8	60	20	19	0.9	0.2	5	No	18
9	55	25	19	0.9	0.2	5	1.55	10
10	50	30	19	0.9	0.2	5	7.3	9
11	45	35	19	0.9	0.2	5	10.1	1

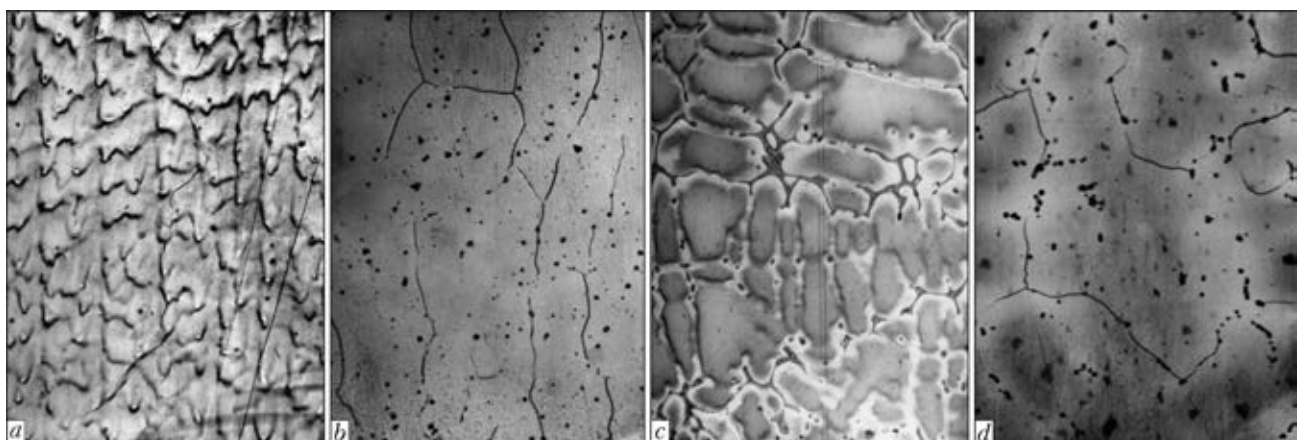


Figure 2. Microstructure ($\times 200$) of ingots of Cu–Mn–Ni system alloys with 20 wt.% Mn (*a, b*) and 25 wt.% Mn (*c, d*) in as-cast condition (*a, c*) and after annealing at 950 °C (*b, d*)

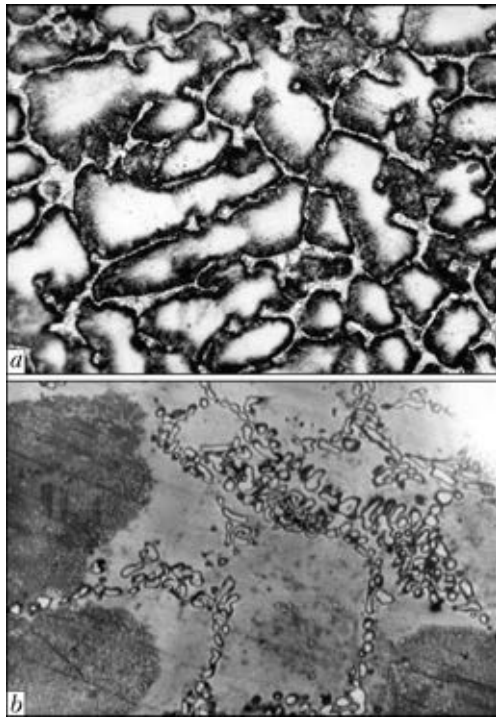


Figure 3. Microstructure ($\times 200$) of ingots of Cu–Mn–Ni system alloys with 35 wt.% Mn in as-cast condition (*a*) and after annealing at 950 °C (*b*)

At further increase of manganese content (30 wt.% in ingot 10), the quantity of second phase is increased, and at 35 wt.% Mn (ingot 11), it fills the entire space between the dendrites (Figure 3, *a*). Analysis of ternary Ni–Mn–Cu diagram [2] shows that at such a component ratio matrix embrittlement and strengthening results from ordering (or precipitation of NiMn type phase).

In the studied alloys the composition of intermetallic phase, precipitating along the crystallite boundaries, differs from precipitates inside the matrix mainly by increased silicon content, which is one of the elements stabilizing the ordered matrix phase. Therefore, silicon presence should facilitate alloy solidification in interdendritic areas of the ingot in the form of intermetallic phase. In this case, annealed alloys are also two-phase (Figure 3, *b*), have an increased hardness and brittleness, and fail along crystallite boundaries at treatment.

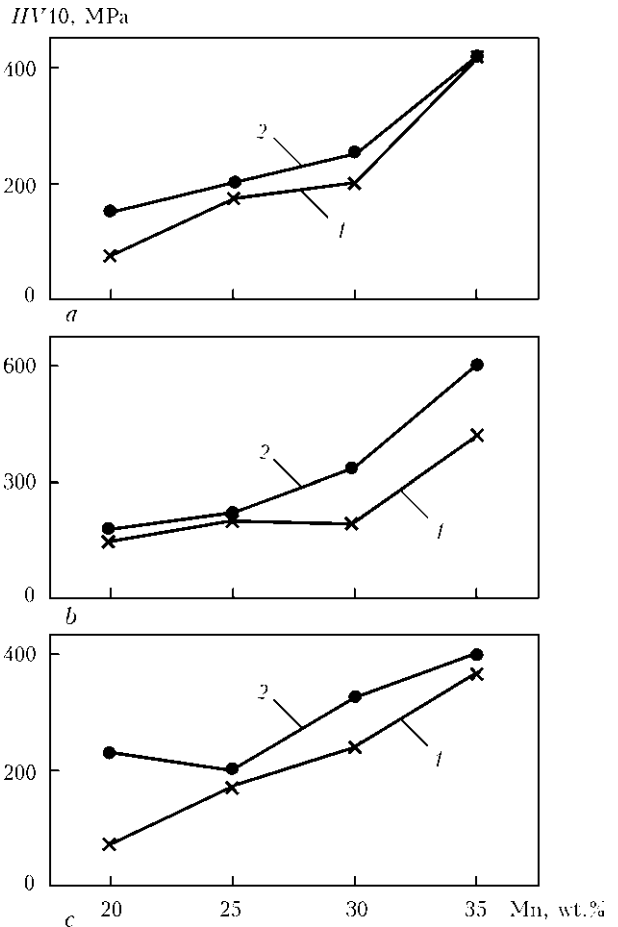


Figure 4. Dependence of microhardness of dendritic (*1*) and interdendritic (*2*) areas for ingots 8–11 on manganese content: *a* – ingot edges; *b* – intermediate part; *c* – ingot central part

Curves reflecting the dependence of microhardness of dendritic and interdendritic areas of cast metal on manganese content, show that at addition of 35 wt.% Mn to the alloy (ingot 11) hardnesses of the matrix and intermetallic interlayers are close or coincide that allows once more assuming the ordered matrix condition (Figure 4). The curves have a characteristic plateau of dendrite hardness in the range of 25–30 % Mn (except for the curve describing the ingot central parts).

Filler with a high content of manganese and appearance of strengthening phases should increase the angle of inclination of the curve that is observed on some graphs (see Figure 4). An

Table 2. Composition and pouring temperature of the alloys

Ingot number	Charge composition, wt.%							Ingot mass, kg	Pouring temperature, °C
	Ni	Mn	Cu	Si	Cr	Mo	Ce		
12	55	25	19	0.8	–	–	–	5	1300
13	52	25	19	0.8	2	0.75	0.3	22	1200
14	52	25	19	0.8	2	0.75	0.3	22	1250
15	52	25	19	0.8	2	0.75	0.3	22	1300

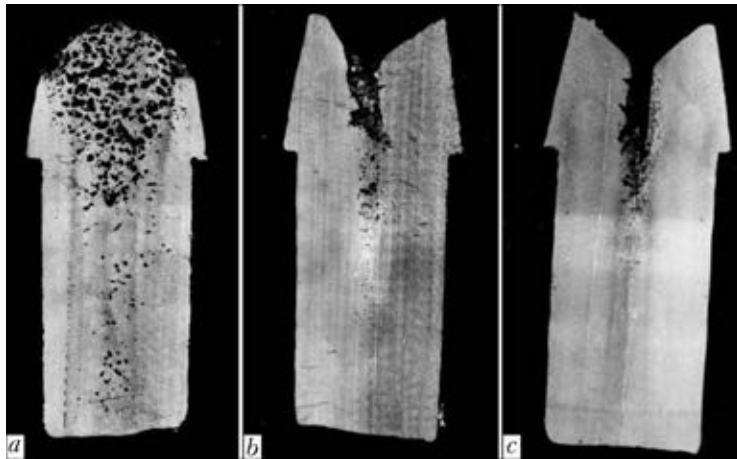


Figure 5. Longitudinal cut of ingots of Ni-Mn-Cu-Si-Cr-Mo-Ce system alloy with different pouring temperature: *a* – 1200; *b* – 1250, *d* – 1300 °C

abrupt change of the trend of the curve at manganese content of 30 wt.% and higher, certainly is indicative of intensive development of the process of strengthening due to ordering.

Mechanical characteristics of the alloys are also in accordance with hardness values. Ingots with low manganese content are readily formable

and ductile, whereas with manganese increase in the alloys their ductility decreases and treatment becomes more complicated. Alloys with 35 wt.% Mn fail at machining and electrical-discharge treatment.

A considerable problem in melting high-manganese alloys is porosity development in the in-

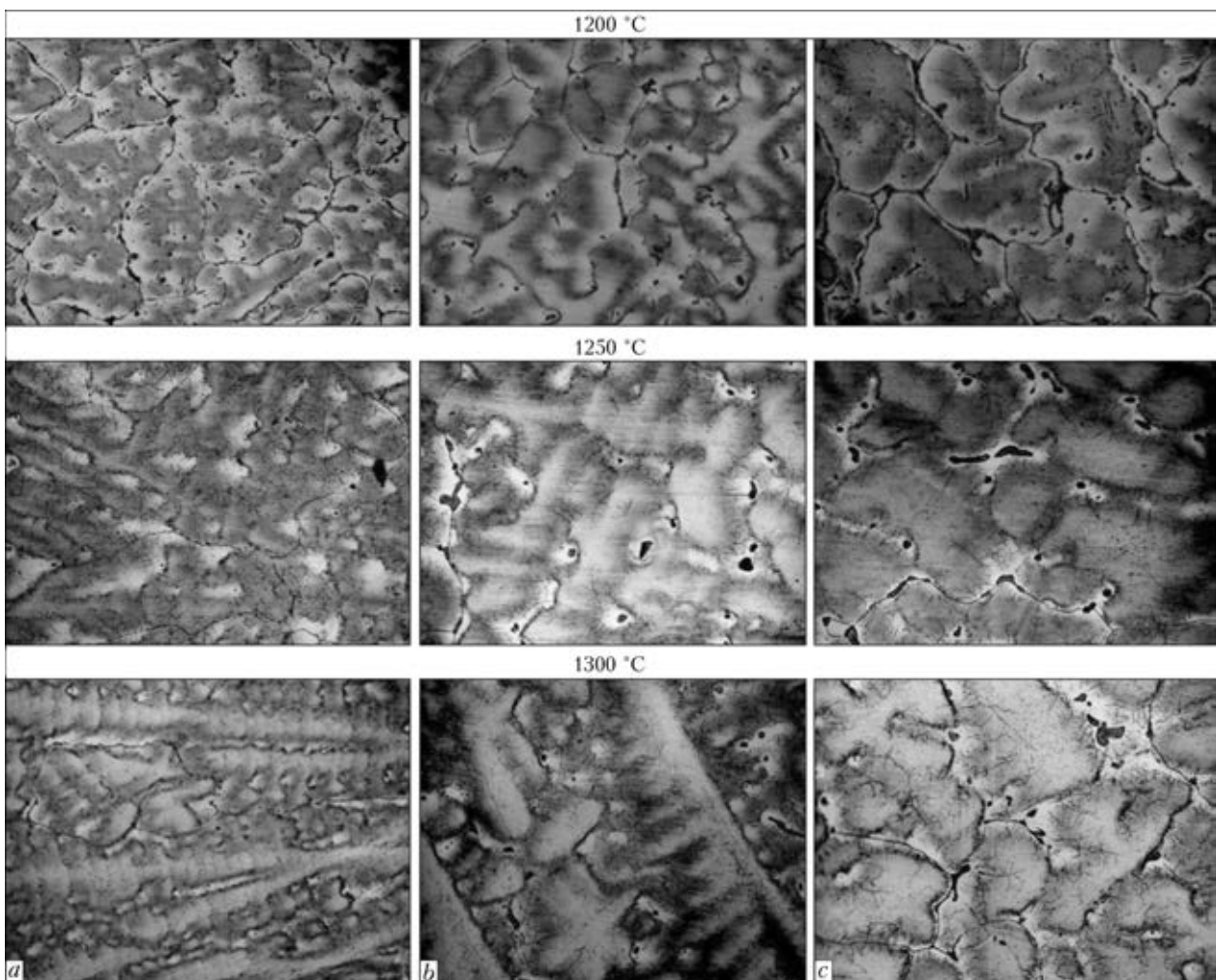


Figure 6. Microstructure (×200) of Ni-Mn-Cu-Si-Cr-Mo system alloys poured at different temperature: *a* – ingot edge; *b* – intermediate part; *c* – ingot central part



Table 3. Composition and mechanical characteristics of test studied alloys

Ingot number	Composition, wt.%								Mechanical characteristics				Shielding atmosphere		
	Ni	Mn	Cu	Si	Cr	Mo	Ce	Al	σ_y , MPa	σ_t , MPa	δ , %	ψ , %			
5	54	25	20	1	-	-	-	0.8	615	970	39	54	«Cryolite» flux		
		23.9	20	0.9				0.22							
6	50	30	19	-	-	-	0.1	0.8	453	760	40	53		Argon (after degassing)	
		23.7	20.7					0.36							
7	53	25	19	1	2	0.75	0.3	-	580	900	41	50			Argon (after degassing)
		22.6	19.8	0.94	2.8	ND									
2	54.8	23.8	20.5	0.87	-	-	-	-	-	-	-	-			
	52.5	22.8	19.9	0.96											
3	54.8	23.8	20.5	0.87	-	1.5	-	-	568	950	36	48	Argon (after degassing)		
	52.5	21.6	0.71	1.44											

Note. Second value of alloy composition is the result of chemical analysis.

gots, which is manifested both in submerged-arc and in argon-arc melting. The regularity of its appearance has not been established, as it is very expensive to melt out a large number of alloys for statistical assessment. Therefore, special experiments were performed to determine the influence of alloy melting temperature on porosity formation (Table 2). Melting was conducted with ANM-10 flux, the application of which is simpler than that of cryolite.

Liquid metal was poured into cast iron moulds. Produced ingots were cut along and ground over the cut surface. It is readily seen (Figure 5) that ingot porosity is reduced with increase of pouring temperature; however, the size of shrinkage cavity is increased. The same regularity was established also at microstructural investigations in different parts of the ingots. Naturally, this is particularly clearly seen, if we compare the structures in the ingot central part (Figure 6), as this is related to the conditions of heat removal from the liquid metal and direction of crystallite growth, respectively.

Obtained results were the basis for conducting further experiments. A number of alloys of the above-considered quaternary system (and also with some additional alloying) with less than 25 wt.% Mn content were melted by submerged-arc and argon-arc process. Obtained ingots were rolled into a square with 25 or 14 mm side, from which specimens were cut out for metallographic studies and samples were taken for chemical analysis. Experimental results are given in Table 3.

From the tabulated data it follows that losses of manganese — an element with a high vapour pressure — are not higher than 1 wt.% in argon-arc melting with preliminary degassing, whereas in submerged-arc melting a large scatter is observed, which is higher than 5 wt.% in some cases.

Filler of small amounts of aluminium, chromium and molybdenum does not essentially affect the mechanical properties of melted metal, namely ductile high-strength alloys were produced. For most of the melts, rupture strength of the alloys was above 90 MPa, while relative

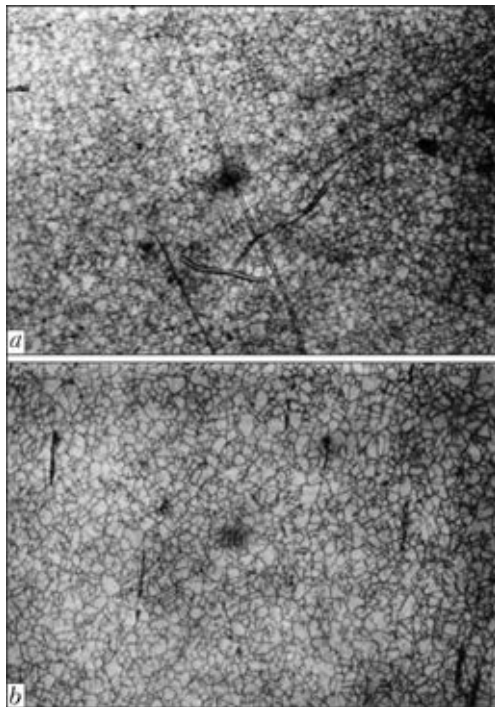


Figure 7. Microstructure ($\times 400$) of Ni-24.3Mn-22.5Cu-0.64Si alloy rolled into a rod with 14 mm side: *a* — in-plane structure normal to the rolling direction; *b* — rod structure along the rolling direction



elongation was about 40 %. Alloy structure is fine-grained solid solution, rolling texture is not clearly manifested. However, grains across the rolling direction are noticeably smaller than those along the rolling direction.

The considered alloys have an acceptable melting range, and they can become widely accepted in industry for brazing steels of various classes, hard alloys and other materials.

Conclusions

1. Melting in argon atmosphere (with preliminary degassing) of Ni–Mn–Cu system alloys with high manganese content allows producing ingots of a more stable composition. However, the difference in quality is not so radical as to override the high cost of this process, compared to submerged-arc melting.

2. Nickel alloys with high manganese content are prone to porosity. One of the methods to solve this problem is to increase pouring temperature.

3. At up to 25 wt.% Mn ductile, high-strength alloys are produced, which are readily formable. At higher manganese content the alloys become harder and more brittle, and do not lend themselves to forming.

4. Braze alloys based on the considered alloys will become widely accepted for brazing steels of different classes, hard alloy and other materials, also in dissimilar combinations.

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