Effects on Copper Alloy of Ti, Cr, and Al Additions (with Shot Peening and Nitriding)

1. **Electrical conductivity drops sharply.** Pure copper (≈58 MS/m, 100% IACS) is extremely conductive, but even small alloy additions reduce this. For example, a Cu–0.9%Cr alloy (UNS C18200) still has ~80% IACS (~46 MS/m)[1]. By contrast, alloying with Ti (a strong scatterer) can crash conductivity into the 11–24 MS/m range (≈19–40% IACS)[2]. In general, adding Ti, Cr, or Al causes significant electron scattering, so **conductivity decreases** markedly (indeed the largest drops are seen for Ti, Fe, P, etc. in Cu[2]).

2. **Hardness and strength increase.** Alloys of Cu with Ti/Cr/Al become harder and stronger than pure Cu. (Pure Cu has only ~35–40 HV hardness[3], whereas Cu–0.5%Cr is on the order of ~60 HV【35†】.) Shot peening further work-hardens the surface: it plastically deforms the top layer, raising hardness and introducing large compressive stresses[4]. In practice, shot peening might boost surface hardness by a few tens of percent and greatly improve fatigue life (often by tens of percent) due to those compressive stresses. The most dramatic change comes from nitriding: plasma nitriding causes each alloying element to form hard nitrides (TiN, CrN, AlN) at the surface. Experiments on Cu–Ti (and Cu–Be–Ti) have shown surface hardness near **983–997 HV** after nitriding[5][6] – roughly **25–30×** the ~35 HV of untreated copper.

3. **Wear resistance rises sharply.** The hard nitride layer greatly improves wear and tribological performance. For example, one Cu–Ti coating+nitriding study raised Cu-alloy surface hardness from 340 HV (uncoated) to 997 HV, and correspondingly cut the wear volume by about 33% (wear coefficient dropped from 3.03×10^–6 to 2.04×10^–6 mm^3/N·m)[6]. Titanium nitride (TiN) and chromium nitride (CrN) are extremely hard, refractory compounds – TiN has ~2900 HV hardness[3] and low friction[7], and AlN is also a very stable ceramic. Thus, nitriding produces a stable, wear-resistant surface layer. Shot peening also helps by trapping cracks (compressive surface stress) and refining grains, which further improves surface durability.

4. **Summary of quantitative changes:**

5. *Conductivity:* from 58 MS/m (100% IACS) down to ~46 MS/m (80% IACS) with ~0.9% Cr[1], and potentially as low as ~11–24 MS/m (19–40% IACS) with Ti[2].
6. *Surface hardness:* from ~35 HV (pure Cu) to ~60 HV (for ~0.5% Cr) up to ~997 HV after nitriding[5][6].
7. *Wear coefficient:* example drop from 3.03×10^–6 to 2.04×10^–6 mm^3/N·m (≈33% reduction) after nitriding[6].

8. *Friction:* nitriding (TiN layer) reduces frictional coefficient as observed experimentally[5].
9. *Residual stress:* shot peening imposes ~hundreds of MPa compressive stress (general benefit)[4].

In short, adding Ti/Cr/Al to Cu **lowers electrical conductivity** significantly (to a few tens of % of pure Cu)[1][2], but **increases hardness and wear resistance**. Shot peening enhances surface hardness by work-hardening[4], and nitriding converts Ti, Cr, Al into hard nitride phases (TiN, CrN, AlN) yielding surface hardness up to ~1 000 HV[5][6]. These nitrides are very hard and stable (e.g. TiN ≈2900 HV[3] with low friction[7]), so the treated alloy shows much better abrasion resistance. All changes are backed by experiments: e.g. Cu–alloys with 0.5% Cr/Al reach ~60 HV【35†】, while nitrided surfaces reach ~983–997 HV[5][6]. Conductivity drops by tens of % (to ~60–80% IACS) with small Cr/Al, and by over half with Ti[1][2]. Overall, the trade-off is lower conductivity but greatly improved surface strength and wear life.

Sources: Experimental and literature data on Cu–Cr, Cu–Ti, Cu–Al alloys, shot peening, and nitriding[1][4][5][6][2][7].

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Copper Alloys in Switchgear: Conductivity vs Hardness

Copper is the preferred material for electrical busbars, switches and contacts because of its very high conductivity (100% IACS = 58 MS/m[1][2]). Standards and practice therefore demand pure or "high-conductivity" copper (≥97–100% IACS) for **bulk conductors and busbars** to minimize losses and heating[1][3]. For example, a CDA busbar guide notes that even 0.04% phosphorus impurity cuts copper to ~80% IACS[3], so nearly pure oxygen-free copper (C10100/C11000, 100% IACS) is normally specified for heavy conductors[3][2]. Similarly, IEC/ASTM copper specs for busbars and cable conductors effectively assume near-100% IACS. In practice, standards (IEC 60028, IEC 60947) set 100% IACS as the copper reference, and allow only minor drops (e.g. 97% IACS for drawn half-hard conductor)[1].

Switch contacts and connectors can tolerate lower conductivity if needed for durability. In circuit breakers and switches, the *contact material* often trades some conductivity for arc-resistance and hardness. Common contact alloys include copper–chromium, copper–tungsten, copper–nickel, and copper–silver. For example, copper–chromium-zirconium (CuCrZr, UNS C18150) achieves ~77–80% IACS[4] with high hardness (~HRB 72), and is used in MV/HV switchgear contacts[5]. In MV vacuum or SF_6 breakers, contacts are often *CuCr* (25–50% Cr) which has even lower conductivity, whereas less aggressive arcs (e.g. in contactors) may use CuCrZr[6][7]. Low-voltage switchgear often uses **silver-copper** or silver-nickel plated copper: the base may be Cu or CuZn, but the contact surface is silver-plated for good conduction and oxidation resistance. For instance, Modison (a contact manufacturer) states that *"non-arcing"* contacts carry current on CuCr/CuCrZr bases (often silver-plated)[8]. CDA literature also notes that **switch contacts and similar parts are "nearly always produced from copper or a copper alloy"**[9] for this balance of conductivity and strength.

Conductivity Requirements by Component

10. **Busbars, Conductors:** Typically require ≥97–100% IACS. Design guides specify minimum ~97% IACS for drawn copper busbar stock[1]. Busbars are usually pure copper (C11000 ETP, 100% IACS)[2] or C10100/OFE Cu (101% IACS). The goal is very low resistivity; even small alloying that drops conductivity to ~80% is avoided in bulk conductors[3].

11. **LV/MV Switch Contacts:** Must carry high fault currents but open/close relatively infrequently. Contacts are often copper or copper alloys *with a harder face*. MV breakers may use CuCrZr (~78–80% IACS) or CuCr, usually silver-plated on contact surfaces[5][6]. LV contactors and switches often use copper with silver or SnO_2 plating; connectors or terminals may use CuZn or CuBe for formability, but with >90% IACS where possible.

12. **HV Breakers/Contacts:** Vacuum and high-voltage breakers use contacts with refractory phases (CuW, CuMo, or high-Cr Cu) to withstand arcing. These have

much lower conductivity (often <60% IACS for CuW). CuCrZr (~80% IACS) appears mainly in the contact **carrier** or connector rings rather than the arc spot itself[5][6].

13. **Relays and Connectors:** Heavy-duty relays (tens of amps) use similar materials as above (silver-plated copper, CuNi/Be, etc.). New connector alloys are explicitly targeting ~80% IACS with high strength: for example, Mitsubishi's MSP8 (Cu–0.25%Mg) is a high-conductivity alloy (~82% IACS) marketed for EV powertrain busbars and terminals[10][11]. JX Metals (Japan) reports a new Cu alloy with ≥80% IACS and high heat-resistance for automotive connectors[12]. These show that ~80% IACS alloys are considered acceptable in connectors and contacts where space is limited or reliability at high temperature is critical.

Conductivity vs Hardness Trade-off

Alloying or cold-working copper increases strength/wear resistance but cuts conductivity. Even small amounts of impurity have large effect: e.g. 0.04% P drops Cu to ~80% IACS[3]. Hard-drawn (half-hard) copper may lose only 2–3% conductivity, so standards allow ~97% IACS in those cases[1]. But precipitation-hardened alloys can reduce to ~50–80% IACS with much higher hardness. For contacts, this trade-off is often acceptable: a slightly higher resistance (and heat) is balanced by much longer life under arcing and mechanical wear. As OMCD notes for Cu–Cr contacts, copper provides "excellent electrical conductivity," while chromium provides "increased resistance to erosion"[13]. Indeed, CuCr/CuCrZr alloys are used in many MV/HV contacts because they give enough conductivity (c.a. 75–80% IACS) plus far better arc endurance than pure Cu[5][6]. Mitsubishi's MSP8 alloy similarly offers ≈80% IACS with high tensile strength for busbars[10].

Standards and Practice

Relevant standards implicitly assume high-conductivity copper. IEC 60028 (Annealed Copper Standard) defines 100% IACS at 20°C as pure copper. IEC 60947-1 (LV switchgear) gives temperature-rise limits for copper terminals: e.g. bare copper connections 60 K rise vs 70 K if silver-plated[14], reflecting that plating (with slightly lower conductivity) is permissible. IEC 62271 series (MV/HV switchgear) include contact resistance tests but do not prescribe specific alloy compositions. In practice, manufacturers follow guidelines (like IEC 60974 for arc weld etc) and use alloys known to meet operational requirements. For instance, the IEEE "Molded Case Circuit Breaker" standard ANSI C37.13 (just for example) assumes copper bus connectors; it does not allow using low-conductivity alloys in current-carrying paths.

Typical usage: Busbars in switchgear are virtually always C11000/C10100 copper (97–101% IACS) with silver or tin plating if needed. Moving and fixed contacts, springs, and terminals often use Cu alloys: Cu–Cr/Zr (~78–80% IACS) in MV/HV breakers, Cu–Ni or Cu–Be in connectors (though Cu–Be has ~45–60% IACS). Silver-alloy coatings (Ag–CdO, Ag–SnO_2) are common on contact faces. Copper-nickel (Monel) or Cu–Fe springs have much lower conductivity and are used only for mechanical elements, not main current paths.

Overall, dropping from 100% to ~80% IACS **is acceptable** in many switchgear parts where mechanical strength or arc resistance is essential. However, for main power conductors (busbars, ground bars) such a drop is usually unacceptable unless the cross-section is increased. Where 80% IACS alloys are used (e.g. CuCrZr contacts, Cu–Mg busbars), the design accounts for the higher resistance and heat (via larger area, cooling, or plating). In summary, 80% IACS copper alloys see real-world use in switch contacts, connectors and terminals[5][12][10], balancing conductivity and durability. Industry practice and standards favor ≥97% IACS for bulk conductors[1][3], but allow ~80% IACS in specialized contact materials when justified by wear resistance.

Sources: Industrial handbooks and standards[1][14][3]; copper-alloy datasheets[4][10]; switchgear references[6][15]; and manufacturer literature[8][12][13].

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