The invention relates to the use of at least one ionic liquid or a mixture of ionic liquids for noncutting forming processes for metallic workpieces.
USE OF IONIC LIQUIDS FOR THE NONCUTTING FORMING OF METALLIC WORKPIECES


[0002] Any foregoing applications, including German patent application DE 10 2007 034 353.3, and all documents cited therein or during their prosecution ("application cited documents") and all documents cited or referenced in the application cited documents, and all documents cited or referenced herein ("herein cited documents"), and all documents cited or referenced in herein cited documents, together with any manufacturer's instructions, descriptions, product specifications, and product sheets for any products mentioned herein or in any document incorporated by reference herein, are hereby incorporated herein by reference, and may be employed in the practice of the invention.

[0003] The invention relates to the use of ionic liquids for the noncutting forming of metallic workpieces according the description herein for purposes such as internal high-pressure forming.

BACKGROUND

[0004] In the noncutting forming of workpieces made of metal, a force is exerted on the workpiece and leads to forming of the metal by flow processes. Examples are forming by pressing, cold flow pressing, drawing, deep drawing and internal high-pressure forming, which is often also referred to as "hydroforming". In these forming processes, friction occurs between the surfaces of the workpiece and the tool used, which can, for example, be a die, punch, draw mould, draw ring or hollow mould. The friction has to be reduced by the use of suitable lubricants since otherwise damage to the tool and/or workpiece can occur, for example as a result of cold welding. In addition, the lubricant can help reduce the force to be applied for forming and also the energy requirement associated therewith.

[0005] Internal high-pressure forming is a specific forming process in which hollow sheet metal parts or sheet metal strips are brought to the desired shape by means of a liquid medium ("pressure medium") in a moulding tool (F. Klooke, W. König, "Fertigungsverfahren 4. Umformtechnik: Umformen", Springer Verlag Berlin, 5th edition, August 2006). Here, the workpiece is widened by means of the internal pressure and at the same time compressed axially. Before widening, the workpiece is introduced into a closed tool and as a result of the internal pressure acquires the shape of the hollow space of the tool. In this process, material can continually be supplied via one end of the tube in order to achieve a desired thickness of the material. The internal pressure of from 200 bar to 3000 bar is transmitted, for example, by a water-oil emulsion, usually at room temperature. The axial force for controlling the thickness of the material of the forming product can be applied via two liquid-tight rams at the ends of the tube. The oil in the forming medium serves to provide lubrication in the process, in particular of valves, and can be provided with biocidal properties.

[0006] The process of internal high-pressure forming is at present preferably employed in areas which require a high degree of forming, in particular in the case of hollow parts. Examples are A-columns, rear axles, catalysts and exhaust pipes in the automobile industry or fittings and water faucets in the bathroom sector.

[0007] A further variant of internal high-pressure forming comprises heating processes which operate in a lower pressure range at elevated temperatures up to about 300°C. This enables, for example, high-grade materials such as aluminium alloys or magnesium alloys to be processed. A heat transfer fluid is used for heating.

[0008] During forming, there is always relative motion between tool and workpiece and thus friction between the surfaces. It is therefore necessary to apply a lubricant between workpiece and tool. In the case of internal high-pressure forming, this is also referred to as external lubrication, while lubrication by means of the pressure medium can also be referred to as internal lubrication. Lubricants known for external lubrication are drawing oils and drawing greases and also soaps on conversion layers such as phosphating layers or Eloxa layers, lubricant surface coatings containing graphite, molybdenum sulphide or Teflon, waxes and drawing films.

[0009] Hydraulic oils are used as pressure media or internal lubrication because of their compressibility up to pressures of about 1500 bar. Alternatives are aqueous media based on water-miscible lubricants containing mineral oil or synthetic lubricants. The lubricant additives added to aqueous pressure media are also referred to as cooling lubricants. Water-oil emulsions are usually employed.

[0010] These previously known lubricants, especially those for external lubrication, each have different disadvantages. Drawing greases and drawing films and likewise lubricant surface coatings can only be applied manually and are therefore unsuitable for mass production. Soap-covered conversion layers are complicated to produce and can, especially in the case of entrainment of the soaps in the pressure medium, lead to undesirable foaming. Lubricant surface coatings can be removed from the finished workpiece only with great difficulty, usually only by means of a grinding process, and remain in pieces either on the tool or on the workpiece. Waxes can get into the pressure medium and, as particles, block the very fine filters of the pressure transducers.

[0011] In general, when choosing the external lubrication and the internal lubrication it has to be ensured that, firstly, the external lubricant can easily be removed from the finished workpiece. Secondly, introduction of external lubrication into the pressure medium can occur at any time during practical use. For this reason, either good separability of the two media is desirable to avoid impairment of the lubricating action and make it possible for the individual media to be reused or, as an alternative, it would be desirable to match the two media to one another so that good compatibility is ensured and only a single homogeneous lubricant system has to be used.

OBJECT OF THE INVENTION

[0012] It is therefore an object of the invention to provide a lubricant for noncutting forming processes which makes a simple handling and an improved property profile possible, ideally with the same lubricant being able to be used as external lubrication, as pressure medium and also as heat transfer fluid.
This is achieved according to the invention by use of at least one ionic liquid or a mixture of ionic liquids according to Claim 1.

The use according to the invention of at least one ionic liquid provides a novel lubricant for noncutting forming processes which can be used as external lubrication, as pressure medium and/or as heat transfer fluid.

It is noted that in this disclosure and particularly in the claims and/or paragraphs, terms such as "comprises", "comprised", "comprising" and the like can have the meaning attributed to it in U.S. Patent law; e.g., they can mean "includes", "included", "including", and the like; and that terms such as "consisting essentially of" and "consists essentially of" have the meaning ascribed to them in U.S. Patent law, e.g., they allow for elements not explicitly recited, but exclude elements that are found in the prior art or that affect a basic or novel characteristic of the invention.

It is further noted that the invention does not intend to encompass within the scope of the invention any previously disclosed product, process of making the product or method of using the product, which meets the written description and enablement requirements of the USPTO (35 U.S.C. 112, first paragraph) or the EPO (Article 83 of the EPC), such that applicant(s) reserve the right and hereby disclose a disclaimer of any previously described product, method of making the product or process of using the product.

This makes it possible for the first time to use a lubricant which can easily be removed from the finished workpiece and displays a property profile which can be adjusted over a wide range in respect of viscosity, density, thermal stability and anticorrosion properties. On this basis, it is possible to produce a tailored lubricant for each forming process, which fully meets requirements in respect of the abovementioned properties.

In addition, use of ionic liquid or a mixture of ionic liquids as lubricant in noncutting forming processes enables simplified handling to be achieved by application of the lubricant being able to be effected in liquid form by means of, for example, spraying or in solid form by means of dipping into a lubricant bath which has been liquefied by heating and subsequent cooling.

Particularly in the case of according to the invention of an ionic liquid or a mixture of ionic liquids as external lubrication in internal high-pressure forming using a water-oil emulsion as pressure medium, preference is given to selecting ionic liquids which are not miscible with the water-oil emulsion and can therefore easily be separated off from the pressure medium. In this way, reuse of the pressure medium can be ensured.

Ionic liquids are in general terms salts which melt at low temperatures (<100° C.) and represent a novel class of liquids which are made up exclusively of ions. In contrast to the classical salt melts, which are high-melting, highly viscous and very corrosive media, ionic liquids are liquid even at low temperatures and have a relatively low viscosity (K. R. Seddon J. Chem. Technol. Biotechnol. 1997, 68, 351-356).

For the purposes of the present invention, ionic liquids are preferably salts of the general formulae I, II or III:

\[
[A]^+ [Y]^-. \tag{I}
\]

where \(n\) is 1, 2, 3 or 4, \([A]^+\) is a quaternary ammonium cation, an oxonium cation, a sulphonium cation or a phosphonium cation and \([Y]^-.\) is a monovalent, divalent, trivalent or tetravalent anion; or

mixed salts of the general formulae (II)

\[
[A]^+ [A]^+ [Y]^-. \tag{IIa}
\]

\[
[A]^+ [A]^+ [A]^+ [Y]^-. \tag{IIb}
\]

\[
[A]^+ [A]^+ [A]^+ [A]^+ [Y]^-. \tag{IIc}
\]

where \([A]^+\), \([A]^+\) and \([A]^+\) are selected independently from the groups mentioned for \([A]^+\) and \([Y]^-.\) as defined for formula I; or

mixed salts of the general formulae (III)

\[
[A]^+ [A]^+ [A]^+ [Y]^-. \tag{IIIa}
\]

\[
[A]^+ [A]^+ [A]^+ [A]^+ [Y]^-. \tag{IIIb}
\]

\[
[A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [Y]^-. \tag{IIIc}
\]

\[
[A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [Y]^-. \tag{IIId}
\]

\[
[A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [Y]^-. \tag{IIIe}
\]

\[
[A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [Y]^-. \tag{IIIf}
\]

\[
[A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [Y]^-. \tag{IIIg}
\]

\[
[A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [Y]^-. \tag{IIII}
\]

\[
[A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [Y]^-. \tag{IIIJ}
\]

\[
[A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [Y]^-. \tag{IIII}
\]

\[
[A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [A]^+ [Y]^-. \tag{IIIII}
\]

where \([A]^+\), \([A]^+\) and \([A]^+\) are selected independently from the groups mentioned for \([A]^+\) and \([Y]^-.\) as defined for formula I and \([M]^+\), \([M]^+\), \([M]^+\) are monovalent metal cations, \([M]^+\) is a divalent metal cation and \([M]^+\) is a trivalent metal cation;

or mixtures of all the formulae (I)-(III).

Ionic liquids preferably comprise anions such as halides, carboxylates, phosphates, thiocyanates, iso-thiocyanates, dicyanamides, sulphonates, alkylsulphonates, sulphonium, alkylsulphonium, tetrafluoroborate, hexafluorophosphate or bis(trifluoromethylsulphonyl)-imide combined with, for example, substituted ammonium, phosphonium, pyridinium or imidazolium cations, with the abovementioned anions and cations representing a small selection from the large number of possible anions and cations and therefore making no claim to completeness or implying any restrictions.

The ionic liquids used according to the invention are preferably composed of at least one quaternary nitrogen and/or phosphorus compound and/or sulphur compound and at least one anion and their melting point is below about 250° C., preferably below about 150° C., in particular below about 100° C. The ionic liquids used according to the invention or their mixtures are particularly preferably liquid at room temperature.

The ionic liquids which are preferably used according to the invention in the noncutting forming process can, for example, comprise at least one cation of the general formulæ:

\[
R^1R^2R^3R^4N^- \tag{IV}
\]

\[
R^1R^2N^- = CR^3R^4 \tag{V}
\]

\[
R^1R^2R^3R^4+ \tag{VI}
\]

\[
R^1R^2R^3R^4+ \tag{VII}
\]

\[
R^1R^2R^3S+ \tag{VIII}
\]
where

R', R, R, R are identical or different and are each hydrogen, a linear or branched aliphatic hydrocarbon radical which has from 1 to 30 carbon atoms and may contain a double bond, a cycloaliphatic hydrocarbon radical which has from 5 to 40 carbon atoms and may contain a double bond, an aromatic hydrocarbon radical having from 6 to 40 carbon atoms, an alkylaryl radical having from 7 to 40 carbon atoms, a linear or branched aliphatic hydrocarbon radical which has from 2 to 30 carbon atoms and is interrupted by one or more groups selected from the group consisting of —C(O)—, (O)—, —(O)—, —(O)—, —NH—, —C(NH)—, —O—, —S(O)2—, —S(O)2—, —S(O)2—, —(O)—, —(O)—, —(O)—, —(O)—, —(O)—, —(O)—, —(O)—, —(O)—, —(O)—, —(O)—, —(O)—, —(O)—, —(O)—, and may contain double bonds, a linear or branched aliphatic or cycloaliphatic hydrocarbon radical which has from 1 to 30 carbon atoms and is functionalized terminally by OR, OR, NH2, N(H)R, or N(O)2 (where R is a C1-C30 alkyl radical which may contain double bonds) and may contain double bonds or a polyether which may have a block or random structure and has the formula —(R1—O)R2—R3.

R is a linear or branched hydrocarbon radical containing from 2 to 4 carbon atoms, and

n is from 1 to 100, preferably from 2 to 60, and

R is hydrogen, a linear or branched aliphatic hydrocarbon radical which has from 1 to 30 carbon atoms that may contain double bonds, a cycloaliphatic hydrocarbon radical which has from 5 to 40 carbon atoms and may contain double bonds, an aromatic hydrocarbon radical having from 6 to 40 carbon atoms, an alkylaryl radical having from 7 to 40 carbon atoms or a —C(O)—R radical where

R is a linear or branched aliphatic hydrocarbon radical which has from 1 to 30 carbon atoms and may contain double bonds, a cycloaliphatic hydrocarbon radical which has from 5 to 40 carbon atoms and may contain double bonds, an aromatic hydrocarbon radical having from 6 to 40 carbon atoms, an alkylaryl radical having from 7 to 40 carbon atoms.

Further possible cations are cations derived from saturated or unsaturated cyclic compounds or aromatic compounds having in each case at least one trivalent nitrogen atom in a 4- to 10-membered, preferably 5- or 6-membered, heterocyclic ring which may be substituted. Such cations can be described in simplified form (i.e. without indication of precise position and number of the double bonds in the molecule) by the general formulae (IX), (X) and (XI) below, where the heterocyclic rings may also contain a plurality of heteroatoms.

Here, R1 and R2 are as defined above,

R is a hydrogen atom, a linear or branched aliphatic hydrocarbon radical which has from 1 to 30 carbon atoms and may contain double bonds, a cycloaliphatic hydrocarbon radical which has from 5 to 40 carbon atoms and may contain double bonds, an aromatic hydrocarbon radical having from 6 to 40 carbon atoms or an alkylaryl radical having from 7 to 40 carbon atoms,

X is an oxygen atom, a sulphur atom or a substituted nitrogen atom (X═O, S, NR).

Examples of cyclic nitrogen compounds of the above-mentioned type are pyrrolidine, dihydropyrrole, pyrrole, imidazoline, oxazoline, oxazole, thiazoline, thiazole, isoxazole, isothiazole, indole, carbazole, piperidine, pyridine, the isomeric picolines and lutidines, quinoline and isoquinoline. The cyclic nitrogen compounds of the general formulae (IX) and (XII) can be substituted (R—H) or mono-substituted or poly-substituted by the radical R, and in the case of multiple substitution by R, the individual radicals R can be different.

Further possible cations are ions derived from saturated acyclic, saturated or unsaturated cyclic compounds or from aromatic compounds having in each case more than one trivalent nitrogen atom in a 4- to 10-membered, preferably 5- or 6-membered, heterocyclic ring. These compounds can be substituted both on the carbon atoms and on the nitrogen atoms. They can also be fused with unsubstituted or substituted benzene rings and/or cyclohexane rings to form poly cyclic structures. Examples of such compounds are pyrazole, 3,5-dimethylpyrazole, imidazole, benzimidazole, N-methylimidazole, dihydropyrazole, pyrazolidine, pyridazine, pyrimidine, pyrazine, 2,3-, 2,5- and 2,6-dimethylpyrazine, cyanoline, phthalazine, quinazoline, phenazine and piperazone. Cations derived from imidazole and its alkyl and phenyl derivatives have been found to be particularly useful as constituents of ionic liquids.

Preference is given to quaternary ammonium salts of alkoxyalkyl fatty acids, also referred to as alkylammonium ester quats, having the generic formula of the type R'R'R'R'N+—A− (IV) in which R1 is an alkyl radical having from 1 to 20 carbon atoms, R2 is an alkyl radical having from 1 to 4 carbon atoms, R3 is a (CH3CH2O)n—H radical where n is from 1 to 200 and R is H or CH3, R is an alkyl radical having from 1 to 4 carbon atoms or a (CH3CH2O)n—H radical where n is from 1 to 200 and R is H or CH3 and A is a monovalent anion.
Among these compounds, preference is given to substances of the formula

\[ R^8-N^\text{II}[(CH_2)_n-Q-R']_m X^- \]  

where each radical \( R^8 \) is independently an alkyl group or hydroxyalkyl group having from 1 to 6 carbon atoms or a benzoyl group, preferably a methyl group.

The radicals \( R' \) are each, independently of one another, hydrogen, a linear or branched alkyl group having from 11 to 22 carbon atoms, a linear or branched alkyl group having from 11 to 22 carbon atoms, with the proviso that at least one radical \( R' \) is not hydrogen.

The radicals \( Q \) are selected independently from among the groups of the formulae:  
- \(-O-C(O)-\)  
- \(-O-C(O)-\)  
- \(-NR^9-C(O)-\)  
- \(-O-C(O)-O-\)  
- \(-CHR^9-O-C(O)-\)  
- \(-CH(\text{COR}^9)-CH_2-O-C(O)-\)  

where \( R^8 \) is hydrogen, methyl, ethyl, propyl or butyl and \( R' \) is hydrogen or methyl, and \( Q \) is preferably \(-O-C(O)-\) or \(-NR^9-C(O)-\).  

\[ m \text{ is from 1 to 4, preferably 2 or 3;} \]

\[ n \text{ is from 1 to 4, preferably 2;} \]

\[ X \text{ is a use-compatible anion, e.g. methylsulphate, ethylsulphate, methysulphonate, butylsulphate, octylsulphate, phosphinate or 2-(2-methoxyethoxy)-ethylsulphate, preferably methylsulphate, 2-(2-methoxyethoxy)ethylsulphate, octylsulphate or phosphinate.} \]

The quaternary ammonium compound can contain mixtures of compounds having different groups \( R' \) which are not hydrogen and whose number extends from 1 up to \( m \). Such mixtures preferably comprise an average of from 1.2 to 2.5 groups \( R' \) which are not hydrogen. The proportion of groups \( R' \) which are different from hydrogen is preferably from 1.4 to 2.0, more preferably from 1.6 to 1.9.

The preferred quaternary ammonium compounds are compounds of the type:

\[ R^9N^\text{II}[CH_2CHR^9OC(O)R'^1]_m X^- \]  

\[ R^9N^\text{II}[CH_2CHR^9OC(O)R'^1]X^- \]  

\[ R^9N^\text{II}[CH_2CHNHR^9(O)]_m X^- \]  

where \( R^9, R'^1 \) and \( X \) have the same meanings as defined above for formula (XII).

The fragment \(-C(O)R^9\) is preferably a fat-containing acyl group. Fat-containing acyl groups which can be used are derived from the natural sources of triglycerides, preferably tallow, vegetable oils, partially hydrogenated tallow and partially hydrogenated vegetable oils. Useful sources of triglycerides are, for example, soybean oil, tallow, partially hydrogenated tallow, palm oil, palm kernels, rapeseed, lard, coconut, rapeseed oil, safflower oil, maize, rice and tallow and mixtures of these components.

A person skilled in the art will know that the composition of the compounds containing fatty acids is subject to certain natural fluctuations, depending on the particular harvest or on the large number of vegetable oil sources. The \( R' \) groups are normal mixtures of linear and branched carbon chains of saturated and unsaturated aliphatic fatty acids.

The proportion of unsaturated groups \( R' \) in such mixtures is preferably at least 10\%, particularly preferably at least 25\% and very particularly preferably from 40\% to 70\%. The proportion of multiply unsaturated groups \( R' \) in such mixtures is less than 10\%, preferably less than 5\% and particularly preferably less than 3\%. If necessary, a partial hydrogenation can be carried out to increase the saturated character and thus improve the stability (e.g. odour, colour, etc) of the end product. The content of unsaturated components, expressed by the iodine number, should be in the range from 5 to 150 and preferably in the range from 5 to 50. The ratio of cis to trans isomers of the double bonds in the unsaturated groups \( R' \) is preferably greater than 1:1 and particularly preferably in the range from 4:1 to 50:1.

Preferred examples of compounds of the formula (XII) are:

\[ N,N-di(tallowoxyethyl)-N,N-dimethylammonium chloride; \]

\[ N,N-di(canolyxoyethyl)-N,N-dimethylammonium chloride; \]

\[ N,N-di(tallowxyethyl)-N-methyl-N-(2-hydroxyethyl)-ammonium methysulphate; \]

\[ N,N-di(canolyxoyethyl)-N-methyl-N-(2-hydroxyethyl)-ammonium methysulphate; \]

\[ N,N-di(tallowylydoethyl)-N-methyl-N-(2-hydroxyethyl)-ammonium methysulphate; \]

\[ N,N-di(tallowxy-2-oxoethyl)-N,N-dimethylammonium chloride; \]

\[ N,N-di(tallowxy-2-oxoethyl)-N,N-dimethylammonium chloride; \]

\[ N,N-di(tallowxy-2-oxoethyl)-N,N-dimethylammonium chloride; \]

\[ N,N-tri(tallowxyethyl)-N,N-dimethylammonium chloride; \]

\[ N,N-tri(canolyxoyethyl)-N,N-dimethylammonium chloride; \]

\[ 1,2-ditallowxyloxy-3-N,N,N-trimethylammonium-propyl chloride; \]

\[ 1,2-dicanoxyloxy-3-N,N,N-trimethylammonium-propyl chloride. \]

Further preferred quaternary ammonium salts are ditallowdimethylammonium chloride, ditallowdimethylammonium methylsulphate, dimethylammonium chloride, di(hydrogenated tallow)dietaryl(dimethylammonium chloride and dibenzyldimethylammonium chloride.

Further possible cations are ions which contain two nitrogen atoms and have the general formula (XII)
may contain double bonds, a cyclo-aliphatic hydrocarbon radical which has from 5 to 40 carbon atoms and may contain double bonds, an aromatic hydrocarbon radical having from 6 to 40 carbon atoms, an alkylaryl radical having from 7 to 40 carbon atoms, a linear or branched aliphatic hydrocarbon radical which has from 1 to 30 carbon atoms and is interrupted by one or more heteroatoms (oxygen, NH, NR, where R is a C₁-C₃₀ alky radical which may contain double bonds) and may contain double bonds, a linear or branched aliphatic hydrocarbon radical which has from 1 to 30 carbon atoms and is interrupted by one or more functions selected from the group consisting of —O—C(O)—, —(O)C—O—, —NH—C(O)—, —(O)C—NH—, —(CH₃)₂N—C(O)—, —(O)C—N(CH₃)₂, —S(O)₂—O—, —O—S(O)₂—, —S(O)₂—NH₂—, —NH—S(O₂)—, —S(O₂)—N(CH₃)₂, —N(CH₃)₂—S(O₂)—, and may contain double bonds, a linear or branched aliphatic or cycloaliphatic hydrocarbon radical which has from 1 to 30 carbon atoms and is functionalized terminally by OH, OR, NH₂, N[R₁][R₂][R₃], where R₁ is a C₁-C₃₀ alky radical which may contain double bonds, and may contain double bonds or a polymer which may have a block or random structure and is made up of —(R₃—O)n—R₆—a.

[0079] where

[0080] R² is a hydrocarbon radical containing from 2 to 4 carbon atoms,

[0081] n is from 1 to 100 and

[0082] R³ is hydrogen, a linear or branched aliphatic hydrocarbon radical which has from 1 to 30 carbon atoms and may contain double bonds, a cycloaliphatic hydrocarbon radical which has from 5 to 40 carbon atoms and may contain double bonds, an aromatic hydrocarbon radical having from 6 to 40 carbon atoms, an alkylaryl radical having from 7 to 40 carbon atoms or a —C(O)—R³ radical where

[0083] R³ is a linear or branched aliphatic hydrocarbon radical which has from 1 to 30 carbon atoms and may contain double bonds, a cycloaliphatic hydrocarbon radical which has from 5 to 40 carbon atoms and may contain double bonds, an aromatic hydrocarbon radical having from 6 to 40 carbon atoms, an alkylaryl radical having from 7 to 40 carbon atoms.

[0084] As very particularly preferred imidazolium ions (XVI), mention may be made of 1-methylimidazolium, 1-ethylimidazolium, 1-(1-butylimidazolium, 1-(1-octyl)imidazolium, 1-(1-tetradecyl)imidazolium, 1-(1-hexadecyl)imidazolium, 1,3-dimethylimidazolium, 1-ethyl-3-methylimidazolium, 1-(1-butyl)-3-methylimidazolium, 1-(1-butyl)-3-ethylimidazolium, 1-(1-hexyl)-3-methylimidazolium, 1-(1-hexyl)-3-ethylimidazolium, 1-(1-hexyl)-3-butylimidazolium, 1-(1-hexyl)-3-butylimidazolium, 1-(1-octyl)-3-butylimidazolium, 1-(1-tetradecyl)3-butylimidazolium, 1-(1-hexadecyl)-3-methylimidazolium, 1-(1-hexadecyl)-3-ethylimidazolium, 1-(1-hexadecyl)-3-butylimidazolium, 1-(1-hexadecyl)-3-butylimidazolium, 1,2,3-trimethylimidazolium, 1-ethyl-2,3-dimethylimidazolium, 1-(1-butyl)-2,3-dimethylimidazolium, 1-(1-hexyl)-2,3-dimethylimidazolium, 1-(1-octyl)-2,3-dimethylimidazolium, 1,4-dimethyl-imidazolium, 1,3,4-trime-thylimidazolium, 1,4-dimethyl-3-ethylimidazolium, 3-butylimidazolium, 1,4-dimethyl-3-octylimidazolium, 1,4,5-trimethylimidazolium, 1,3,4,5-tetramethylimidazolium, 1,4,5-trimethyl-3-ethylimidazolium, 1,4,5-trimethyl-3-butylimidazolium and 1,4,5-trimethyl-3-octylimidazolium.

[0085] Further possible cations are ions which, in particular, are made up of the abovementioned cations as a result of dimerization, trimimerization or polymerization to form dication, trication or polycations. These include dications, trications and polycations which have a polymeric backbone, for example one based on siloxanes, polyethers, polyesters, polyamides or polyacrylates, in particular branched and hyperbranched polymers.

[0086] In a preferred embodiment of the present invention, use is made of ionic liquids in which the cation [A⁺] is a pyridinium ion (XVIIa),

![Diagram](XVIIa)

[0087] where

[0088] one of the radicals R₁ to R₅ is methyl, ethyl or chlorine and the remaining radicals R₁ to R₅ are hydrogen:

[0089] R₁ is dimethylamino and the remaining radicals R₁, R₂, R₃ and R₅ are hydrogen;

[0090] all radicals R₁ to R₅ are hydrogen;

[0091] R₁ is carboxy or carbamidomethyl and the remaining radicals R₁, R₂, R₄ and R₅ are hydrogen; or

[0092] R₁, R₃ or R₅ and R₇ are 1,4-buta-1,3-diyl and the remaining radicals R₁, R₂, R₄ and R₅ are hydrogen;

[0093] in particular one in which

[0094] R₁ to R₅ are each hydrogen; or

[0095] one of the radicals R₁ to R₅ is methyl or ethyl and the remaining radicals R₁ to R₅ are hydrogen. As very particularly preferred pyridinium ions (XVIIa), mention may be made of 1-methylpyridinium, 1-ethylpyridinium, 1-(1-butyl)pyridinium, 1-(1-hexyl)pyridinium, 1-(1-octyl)pyridinium, 1-(1-tetradecyl)pyridinium, 1-(1-hexadecyl)pyridinium, 1,2-dimethylpyridinium, 1-ethyl-2-methylpyridinium, 1-(1-butyl)-2-methylpyridinium, 1-(1-hexyl)-2-methylpyridinium, 1-(1-octyl)-2-methylpyridinium, 1-(1-tetradecyl)-2-methylpyridinium, 1-(1-hexadecyl)-2-methylpyridinium, 1,2-dimethyl-5-ethylpyridinium, 1,5-diethyl-2-methylpyridinium, 1-(1-butyl)-2-methyl-3-ethylpyridinium,
1-(1-hexyl)-2-methyl-3-ethylpyridinium and 1-(1-oc-
tyl)-2-methyl-3-ethylpyridinium, 1-(1-dodecyl)-2-me-
thyl-3-ethylpyridinium, 1-(1-tetradecyl)-2-methyl-3-
ethylpyridinium and 1-(1-hexadecyl)-2-methyl-3-
ethylpyridinium.

Very particular preference is also given to ionic li-
quids in which the cation [A]\(^+\) is a pyridazinium ion (XVIIb),

where

- R\(_1\) to R\(_4\) are each hydrogen; or
- one of the radicals R\(_1\) to R\(_4\) is methyl or ethyl and the remaining radicals R\(_1\) to R\(_4\) are hydrogen.

Very particular preference is also given to ionic li-
quids in which the cation [A]\(^+\) is a pyrimidinium ion (XVIIc),

where

- R is hydrogen, methyl or ethyl and R\(_1\) to R\(_4\) are each, independently of one another, hydrogen or methyl;
- R\(_1\) is hydrogen, methyl or ethyl, R\(_2\) and R\(_4\) are each methyl and R\(_3\) is hydrogen.

Very particular preference is also given to ionic li-
quids in which the cation [A]\(^+\) is a pyrazinium ion (XVIId),

where

- R\(_1\) is hydrogen, methyl or ethyl and R\(_2\) to R\(_4\) are each, independently of one another, hydrogen or methyl;
- R\(_1\) is hydrogen, methyl or ethyl, R\(_2\) and R\(_4\) are each methyl and R\(_3\) is hydrogen.

Very particular preference is also given to ionic li-
quids in which the cation [A]\(^+\) is a pyrazolium ion (XVIIe),

where

- R\(_1\) to R\(_4\) are each, independently of one another, hydrogen or methyl.

Very particular preference is also given to ionic li-
quids in which the cation [A]\(^+\) is a pyrazolium ion (XVIIe'),

where

- R\(_1\) to R\(_4\) are each, independently of one another, hydrogen or methyl.

Very particular preference is also given to ionic li-
quids in which the cation [A]\(^+\) is a 1-pyrazolinium ion (XVIII),

where

- R\(_1\) to R\(_4\) are each, independently of one another, hydrogen or methyl.
Very particular preference is also given to ionic liquids in which the cation $[A]^+$ is a 2-pyrazolinium ion (XVII).

\[
\text{(XVII)}
\]

where

$R$ is hydrogen, methyl, ethyl or phenyl and $R_2$ to $R_6$ are each, independently of one another, hydrogen or methyl.

Very particular preference is also given to ionic liquids in which the cation $[A]^+$ is a 3-pyrazolinium ion (XVIIk) or (XVIIk').

\[
\text{(XVIIk)}
\]

where

$R$ and $R_2$ are each, independently of one another, hydrogen, methyl or ethyl and $R_3$ to $R_6$ are each, independently of one another, hydrogen or methyl.

Very particular preference is also given to ionic liquids in which the cation $[A]^+$ is an imidazolinium ion (XVIIIm) or (XVIIIm').

\[
\text{(XVIIIm)}
\]

where

$R$ to $R_2$ are each, independently of one another, hydrogen, methyl or ethyl and $R_3$ to $R_6$ are each, independently of each other, hydrogen or methyl.

Very particular preference is also given to ionic liquids in which the cation $[A]^+$ is an imidazolinium ion (XVIIIn) or (XVIIIn').

\[
\text{(XVIIIn)}
\]

where

$R_1$ to $R_3$ are each, independently of one another, hydrogen, methyl or ethyl and $R_4$ to $R_6$ are each, independently of one another, hydrogen or methyl.

Very particular preference is also given to ionic liquids in which the cation $[A]^+$ is a thiazolium ion (XVIIo) or (XVIIo') or an oxazolium ion (XVIIp).

\[
\text{(XVIIo)}
\]

where

$R_1$ to $R_3$ are each, independently of one another, hydrogen, methyl or ethyl and $R_4$ to $R_6$ are each, independently of one another, hydrogen or methyl.

Very particular preference is also given to ionic liquids in which the cation $[A]^+$ is a thiazolium ion (XVIIo) or (XVIIo') or an oxazolium ion (XVIIp).

\[
\text{(XVIIo')}
\]

where

$R_1$ and $R_2$ are each, independently of one another, hydrogen, methyl or ethyl, 1-butyl or phenyl. $R_3$ and $R_4$ are each, independently of one another, hydrogen, methyl or ethyl and $R_5$ and $R_6$ are each, independently of one another, hydrogen or methyl.
where

**[0136]** $R_1$ is hydrogen, methyl, ethyl or phenyl and $R_2$ and $R_3$ are each, independently of one another, hydrogen or methyl.

**[0137]** Very particular preference is also given to ionic liquids in which the cation $[A]^+$ is a 1,2,4-triazolium ion (XVIIq), (XVIIq') or (XVIIq'').

**[0138]** where

**[0139]** $R_1$ and $R_2$ are each, independently of one another, hydrogen, methyl, ethyl or phenyl and $R_3$ is hydrogen, methyl or phenyl.

**[0140]** Very particular preference is also given to ionic liquids in which the cation $[A]^+$ is a 1,2,3-triazolium ion (XVIIr), (XVIIr') or (XVIIr'').

**[0141]** where

**[0142]** $R_1$ is hydrogen, methyl or ethyl and $R_2$ and $R_3$ are each, independently of one another, hydrogen or methyl or $R_2$ and $R_3$ together are 1,4-buta-1,3-diylene.

**[0143]** Very particular preference is also given to ionic liquids in which the cation $[A]^+$ is a pyrrolidinium ion (XVIIis),

**[0144]** where

**[0145]** $R_1$ is hydrogen, methyl, ethyl or phenyl and $R_2$ to $R_4$ are each, independently of one another, hydrogen or methyl.

**[0146]** Very particular preference is also given to ionic liquids in which the cation $[A]^+$ is an imidazolidinium ion (XVIIit),

**[0147]** where

**[0148]** $R_1$ and $R_4$ are each, independently of one another, hydrogen, methyl, ethyl or phenyl and $R_2$ and $R_3$ and also $R_5$ to $R_6$ are each, independently of one another, hydrogen or methyl.

**[0149]** Very particular preference is also given to ionic liquids in which the cation $[A]^+$ is an ammonium ion (XVIII),

**[0150]** where

**[0151]** $R_1$ to $R_5$ are each, independently of one another, $C_1$-$C_{18}$-alkyl; or

**[0152]** $R_2$ to $R_5$ are each, independently of one another, hydrogen or $C_1$-$C_{18}$-alkyl and $R_6$ is 2-hydroxyethyl; or
[0153] \(R_1\) and \(R_2\) together are 1,5-pentylene or 3-oxa-1,5-pentylene and \(R_3\) is \(C_{1-18}\)-alkyl, 2-hydroxyethyl or 2-cyanoethyl.

[0154] As particularly preferred ammonium ions (XVIII), mention may also be made of methyltr(1-butyl)ammonium, 2-hydroxyethylammonium, bis(2-hydroxyethyl)dimethylammonium, N,N,N,N-dimethylperidinium and N,N-dimethylmorpholinium.

[0155] Particular preference is also given to ionic liquids in which the cation \([A]^+\) is a guanidinium ion (XVIIIv),

\[
\begin{align*}
\text{(XVIIIv)} & \quad \text{where} \\
R_1 & \text{to } R_5 \text{ are each methyl;} \\
R_1 & \text{to } R_2 \text{ are each, independently of one another, } C_{1-18}\text{-alkyl;} \\
R_1 & \text{to } R_5 \text{ are each, independently of one another, } C_{1-18}\text{-alkyl or 2-hydroxyethyl.}
\end{align*}
\]

As very particularly preferred guanidinium ion (XVIIIv), mention may be made of \(N,N',N'',N'''\)-hexamethylguanidinium.

[0156] Very particular preference is also given to ionic liquids in which the cation \([A]^+\) is a derivative of an ethanolamine, e.g. a cholinium ion (XIXw), or of a diethanolamine (XIXw') or of a triethanolamine (XIXw") or of a triethanolamine (XIXw")

[0162] where \(R_1\) and \(R_2\) are each, independently of one another, methyl, ethyl, 1-butyl or 1-octyl and \(R_3\) is hydrogen, methyl, ethyl, acetyl, \(-\text{SO}_2\text{OH}\) or \(-\text{PO(OH)}_2\); or

[0163] \(R_1\) and \(R_2\) are each, independently of one another, methyl, ethyl, 1-butyl or 1-octyl and \(R_3\) is hydrogen, methyl, ethyl, acetyl, \(-\text{SO}_2\text{OH}\) or \(-\text{PO(OH)}_2\); or

[0164] \(R_1\) is methyl, ethyl, 1-butyl or 1-octyl, \(R_2\) is a \(-\text{CH}_2\text{-CH}_2\text{-OR}_4\) group and \(R_3\) and \(R_4\) are each, independently of one another, hydrogen, methyl, ethyl, acetyl, \(-\text{SO}_2\text{OH}\) or \(-\text{PO(OH)}_2\); or

[0165] \(R_1\) is a \(-\text{CH}_2\text{-CH}_2\text{-OR}_4\) group, \(R_2\) is a \(-\text{CH}_2\text{-CH}_2\text{-OR}_4\) group and \(R_3\) to \(R_6\) are each, independently of one another, hydrogen, methyl, ethyl, acetyl, \(-\text{SO}_2\text{OH}\) or \(-\text{PO(OH)}_2\).

[0166] \(R_1\) is methyl, ethyl, 1-butyl, 1-octyl, acetyl, \(-\text{SO}_2\text{OH}\) or \(-\text{PO(OH)}_2\) and \(R_2\) to \(R_6\) are, independently of one another, hydrogen, methyl, ethyl, acetyl, \(-\text{SO}_2\text{OH}\), \(-\text{PO(OH)}_2\) or \(-(\text{C}_n\text{H}_{2n+1})_x\text{R}_6\) where \(n=1\) to 5 and \(m=1\) to 100.

[0167] Very particular preference is given to ionic liquids in which the cation \([A]^+\) is a phosphonium ion (VI) in which \(R_1\) to \(R_5\) are each, independently of one another, \(C_{1-18}\) alkyl, in particular butyl, isobutyl, 1-hexyl or 1-octyl.

[0168] Among the above-mentioned cations, preference is given to the pyridinium ions (XVIIa), imidazolium ions (XVI) and ammonium ions (XVIII), in particular 1-methylpyridinium, 1-ethylpyridinium, 1-(1-butyl)pyridinium, 1-(1-hexyl)pyridinium, 1-(1-octyl)pyridinium, 1-(1-dodecyl)pyridinium, 1-(1-tetradecyl)pyridinium, 1-(1-hexadecyl)pyridinium, 1,2-dimethylpyridinium, 1-ethyl-2-methylpyridinium, 1-(1-butyl)-2-methylpyridinium, 1-(1-hexyl)-2-methylpyridinium, 1-(1-octyl)-2-methylpyridinium and 1-(1-tetradecyl)-2-methylpyridinium.

[0169] The metal cations \([M]^{1+}\), \([M]^{2+}\), \([M]^{3+}\), \([M]^{4+}\) and \([M]^{5+}\) mentioned in the formulae (IIia) to (IIIj) are generally metal cations of Groups 1, 2, 6, 7, 8, 9, 10, 11, 12 and 13 of the Periodic Table. Suitable metal cations are, for example, \(\text{Li}^+, \text{Na}^+, \text{K}^+, \text{Ca}^{2+}, \text{Ba}^{2+}, \text{Sr}^{2+}, \text{Fe}^{2+}, \text{Fe}^{3+}, \text{Co}^{2+}, \text{Cu}^{2+}, \text{Ag}^+, \text{Zn}^{2+}\) and \(\text{Al}^{3+}\).
The anion $[Y]^-$ of the ionic liquid is, for example, selected from:

- halides and halogen-containing compounds of the formulae: $F^-$, $Cl^-$, $Br^-$, $I^-$, $BF_4^-$, $PF_6^-$, $AlCl_4^-$, $Al_2Cl_7^-$, $AlBr_4^-$, $FeCl_4^-$, $BCl_4^-$, $SiF_6^-$, $AsF_5^-$, $ZnCl_2^-$, $SnCl_4^-$, $CuCl_2^-$, $CF_3SO_3^-$, $CF_3CO_2^-$, $CCl_2CO_2^-$, $CN^-$, $SCN^-$, $OCN^-$, $NO_2^-$, $NO_3^-$, $N(CN)$.

- sulphates, sulphites and sulphonates of the general formulae: $SO_4^{2-}$, $HSO_4^-$, $SO_3^{2-}$, $HSO_3^-$, $R^1OSO_3^-$, $R^2SO_3^-$.

- phosphates of the general formulae: $PO_4^{3-}$, $HPO_4^{2-}$, $R^1PO_4^-$, $HR^2PO_4^-$, $R^3PO_4^-$.

- phosphites and phosphinates of the general formulae: $R^4HPO_3^-$, $R^5RP_2O_5$.

- the group of phosphites of the general formulae: $PO_3^{2-}$, $HPO_3^-$, $R^1PO_3^-$, $R^2RP_2O_5$.

- the group of phosphite phosphinates of the general formulae: $R^4HPO_3^-$, $R^5RP_2O_5$.

- the group of phosphonites and phosphinates of the general formulae: $R^6HPO_2^-$, $R^7RP_2O_6$.

- the group of boronates of the general formulae: $B(OH)_4^-$. The general formulae: $R^8BO_3^-$, $R^9BO_2^-$.

- the group of boronates and carbonic esters of the general formulae: $HCO_2^-$, $CO_2^-$, $R^1CO_2^-$.

- the group of carboxylates of the general formulae: $HO_2^-$, $CO_2^-$, $R^1CO_2^-$.

- the group of silicates and silicic esters of the general formulae: $SiO_4^{2-}$, $HSiO_3^-$, $H_2SiO_3^-$, $R^1SiO_3^-$, $R^2SiO_3^-$, $R^3SiO_3^-$, $R^4SiO_3^-$, $R^5SiO_3^-$, $R^6SiO_3^-$, $R^7SiO_3^-$.

- the group of alkylsilanes or aryldisilanes of the general formulae: $R^8SiO_3^-$, $R^9SiO_3^-$, $R^{10}SiO_3^-$, $R^{11}SiO_3^-$, $R^{12}SiO_3^-$, $R^{13}SiO_3^-$.

- the group of carbamates, bis(sulfonium)imides and sulphonylimides of the general formulae:

\[
\begin{align*}
\text{SO}_3^+ & \quad \text{R}^1
\end{align*}
\]

- the group of carboximides, bis(sulfonium)imides and sulphonylimides of the general formulae:

\[
\begin{align*}
\text{SO}_3^+ & \quad \text{R}^1
\end{align*}
\]
3-ethylphenyl, 4-ethylphenyl, 2,3-dimethylphenyl, 2,4-dimethylphenyl, 2,5-dimethylphenyl, 2,6-dimethylphenyl, 3,4-dimethylphenyl, 3,5-dimethylphenyl, 4-phenylphenyl, 1-naphthyl, 2-naphthyl, 1-pyrrolyl, 2-pyrrolyl, 3-pyrrolyl, 2-pyridinyl, 3-pyridinyl, 4-pyridinyl or C5F3-C6H1 where 0≤n≤5 or

[0196] two radicals form an unsaturated, saturated or aromatic ring which may be substituted by functional groups, aryl, alkyl, ariloxy, alkoxy, halogen, heteroatoms and/or heterocycles and may be interrupted by one or more oxygen and/or sulfur atoms and/or one or more more substituted or unsubstituted imino groups.

[0197] Very particularly preferred anions are, for example, chloride, bromide, iodide, thiocyanate, hexafluoro-phosphate; trifluoromethanesulphonate; methanesulphonate; formate; acetate; glycolate; lactate; mandelate; nitrate; nitrite; trifluoroacetate; sulphate; hydrogen sulphate; methyl sulphate; ethyl sulphate; 1-propyl sulphate; 1-butyl sulphate; 1-hexyl sulphate; 1-octyl sulphate; dihydrogen phosphate; hydrogen phosphate; C4-C6 dialkyl phosphates; propionate; tetrachloroaluminate; AlCl4-; chlorozincate; chlorofluorosilicates; bis(trifluoromethyl-sulphonyl)imide; bis(pentafluorophenyl)phosphinate; bis(methylsulphonyl)imide; bis(p-toluenesulphonyl)-imide; tris(trifluoromethylsulphonyl)methide; bis(pentafluoroethylsulphonyl)methide; p-toluene-sulphonate; tetracarbonyloxyborate; dimethylglyoxyl monoethyl ether sulphate; oleate; stearate; acrylate; methacrylate; maleate; glycolic acid; vinyl phosphate; bis(pentafluorophenyl)phosphate; borates such as bis[salicylato(2-)]borate; bis[oxybis(2-)]borate; bis[1,2-benzoldiolato(2-)]O-borate; tetra-cyanoborate, tetrafluoroborate; dicyanamide; tris(pentafluoroethyl)trifluorophosphate; tris(hexafluorophenyl)trifluorophosphate, cyclic arylphosphates such as catecholphosphate (CrH4O3)PO3O- and chloroborate.

[0198] Preferred anions are selected from the group consisting of, without making any claim as to completeness, halides bis(perfluoroalkylsulphonyl)amides and bis(perfluoroalkylsulphonylimides such as bis(trifluoromethylsulphonyl)imide, alkyltosylates and arylosulphates, perfluoroalkyltosylates, nitrate, sulphate, hydrogen sulphate, alkylosulphates and arylsulphates, polyelectrolyte sulphates and phosphonates, perfluoroalkylsulphonates, sulphonate, alkylosulphonates and arylsulphonates, alkylcarboxylates and aryl-carboxylates, perfluorooalkylcarboxylates, perchlorate, tetrachloroaluminate, succinimide. Further preferred anions are dicyanamide, thiocyanate, isothiocyanate, tetraphenyborate, tris(hexafluorophenyphosphor)borate, tetrafluoroborate, hexafluorophosphate, polyelectrolyte phosphates and phosphate.

[0199] Very particularly preferred anions are chloride, bromide, hydrogen sulphate, tetrachloroaluminate, thiocyanate, methylsulphate, ethyl sulphate, methanesulphonate, formate, acetate, glycolate, lactate, dimethyl phosphate, diethylphosphate, p-toluene sulphonate, tetrafluoroborate and hexafluoro-phosphate.

[0200] In a further particularly preferred embodiment of the invention, use is made of ionic liquids or mixtures thereof which contain a combination of 1,3-dialkyl-imidazolium, 1,2,3-trialkylimidazolium, 1,3-dialkyl-imidazolium or 1,2,3-trialkylimidazolium cation with an anion selected from the group consisting of halides, bis(trifluoromethylsulphonylimide, per-fluoroalkylsulphates, alkylosulphonates and alkyl sulphonates, perfluorinated alkylosulphonates and alkylsulphonates, perfluoroalkylcarboxylates, perchlorate, dicyanamide, thiocyanate, isothiocyanate, tetraphenyborate, tetrakis(hexafluorophenyphosphor)borate, tetrafluoroborate, hexafluorophosphate.

[0201] Furthermore, it is also possible to use simple, commercially available, acyclic quaternary ammonium salts such as TEGO® IL T16ES, TEGO® IL K5MS, TEGO® IL DS or TEGO® IL 2MS (products of Evonik Goldschmidt GmbH).

[0202] Owing to the fact that some ionic liquids can be selected so as to have a property profile so that they are stable at high temperatures, noncombustible, corrosion-inhibiting and easy to wash from the finished workpiece, these ionic liquids can be used advantageously as external lubrication, as pressure medium and as heat transfer fluid, in particular in internal high-pressure forming. In addition, ionic liquids do not display any vapour pressure below their decomposition temperature.

[0203] Furthermore, particular preference is given to selecting ionic liquids which are biodegradable and at the same time nontoxic. Apart from the abovementioned advantages, these two additional properties are important criteria in the choice of lubricants for mass production in an industrial environment.

[0204] Compared to the previous systems for internal high-pressure forming using a lubricant coating, for example graphite, and aqueous pressure media as water-oil emulsions, the finished workpiece and also the workpiece surface can be cleaned more easily of the external lubrication when ionic liquids are used as external lubricant, which is of particular importance for mass production. In addition, the ionic liquid used as external lubrication can be chosen so that it is not miscible with the emulsion pressure medium. In this case, the pressure medium in the form of the water-oil emulsion can advantageously be reused. In addition, the viscosity of the ionic liquid can be matched to the requirement profile. Firstly, it is desirable for the external lubrication not to run off, but on the other hand the lubricant must not be so viscous that it is difficult to remove.

[0205] In an advantageous embodiment of the invention, the ionic liquid used as external lubrication in a noncutting forming process or the mixture of ionic liquids can have a melting point above room temperature. In this case, the workpiece can, for example, be dipped into a bath of the external lubrication which has been liquefied by heating in order to be provided on the outside with the lubrication before forming. When the workpiece cools, the external lubrication solidifies and the workpiece can be inserted into the tool without further contamination. After forming, the external lubrication can either be liquefied by heating and thus removed or it can be washed off the workpiece by means of an aqueous washing solution.

[0206] The choice of the ionic liquid or the mixture of ionic liquids is made according to the requirement profile for the forming process selected.


[0208] In a preferred embodiment of the invention, the noncutting forming process is internal high-pressure forming. In this process in particular, the ionic liquid or the mixture
of ionic liquids with their above-described property profile can achieve great simplification.

[0209] The ionic liquid or the mixture of ionic liquids can preferably be used as external lubrication and/or as pressure medium and/or as heat transfer fluid. In particular, the simultaneous use as external lubrication and as pressure medium is accompanied by further synergies since incompatibility of the two media is ruled out here and only a single environmentally friendly lubricant is used. In addition, the high pressure and temperature stability of the ionic liquid combined with the ease with which it can be washed off the finished workpiece make excellent results and improved mass production possible.

[0210] In a further embodiment of the present invention, the ionic liquid or the mixture of ionic liquids has a melting point below 100°C and preferably below 50°C.

[0211] The ionic liquid or the mixture of ionic liquids can particularly preferably have a liquid range from −50°C to 400°C, preferably from −40°C to 380°C and particularly preferably from −30°C to 350°C.

[0212] A further preferred embodiment of the invention provides for the use of an ionic liquid or a mixture of ionic liquids having a decomposition temperature above 300°C.

[0213] This ensures that the ionic liquid used as external lubrication, as pressure medium and/or as heat transfer fluid has a sufficient thermal stability for repeated use in mass production to be possible.

[0214] In summary, use of at least one ionic liquid or of mixtures of ionic liquids for noncutting forming, by means of which considerable simplification of manufacturing processes can be achieved, is proposed. Owing to the fact that the ionic liquid has a property profile which can be tailored so that the liquid is stable at high temperatures, noncombustible, corrosion-inhibiting and can easily be washed off the finished workpiece, it can advantageously be used as external lubrication, as pressure medium and as heat transfer fluid, especially in internal high-pressure forming. In addition, ionic liquids do not display any vapour pressure below the decomposition temperature, are biodegradable and are nontoxic.

EXAMPLES

[0215] In the examples presented below, the present invention is described by way of example without the invention, whose scope is determined by the total description and the claims, being restricted to the embodiments mentioned in the examples.

Experimental Procedure

[0216] Forming experiments using identical steel tubes (same material (St 52 name according to German industrial norm DIN 17100), same wall thickness (3 mm), same length (280 mm) and diameter (50 mm)) were carried out in a hydraulic three-column press (Dunkes Maschinenbau 18S 3 1500) at a pressing force of 15000 kN. The steel tubes were painted uniformly with the lubricant and then placed in the press. A simple T-piece was used as tool.

[0217] In the first series of experiments, the spacing of the vertical column was kept constant (spacing Z5) and the area formed in the forming process at the top of the resulting T-piece by direct contact with the piston of the vertical column was measured. This area is greater the better the lubrication and is thus a measure of the quality of the lubricant.

<table>
<thead>
<tr>
<th>Lubricant</th>
<th>Max. pressure [bar]</th>
<th>Spacing Z5 [mm]</th>
<th>Area [mm²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tego II. IM55</td>
<td>1000</td>
<td>65</td>
<td>573</td>
</tr>
<tr>
<td>Tego II. T16ES</td>
<td>1000</td>
<td>65</td>
<td>475</td>
</tr>
<tr>
<td>IL 3</td>
<td>1000</td>
<td>65</td>
<td>409</td>
</tr>
<tr>
<td>Hydredraw 768</td>
<td>1000</td>
<td>65</td>
<td>355</td>
</tr>
</tbody>
</table>

Hydredraw 768 is a high-performance lubricant for hydroforming which is based on mineral oil and is marketed by the DA Stuart Company.

[0218] Tego II. IM55 = 1-ethyl-4,5-dihydro-3-(2-hydroxyethyl)-2-(8-heptadecenyl)-1H-imidazolium ethylsulphate CAS No. 68039-12-3

[0219] Tego II. T16ES = tetraalkylylammonium sulphate, CAS No. 68071-95-4

IL 3 = dimethylidiallyl ammonium acetate

[0220] Tego II. IM55 = 1-ethyl-4,5-dihydro-3-(2-hydroxyethyl)-2-(8-heptadecenyl)-1H-imidazolium ethylsulphate CAS No. 68039-12-3

[0221] Tego II. T16ES = tetraalkylylammonium sulphate, CAS No. 68071-95-4

IL 3 = dimethylidiallyl ammonium acetate

In the second series of experiments, the spacing of the vertical column was increased in steps of 0.5 mm until the tube ruptured during the forming process. A greater maximum height of the formed T-piece (greater Δ spacing Z5) means better lubrication during the forming process and thus corresponds to a higher lubricant quality.

<table>
<thead>
<tr>
<th>Lubricant</th>
<th>Max. pressure [bar]</th>
<th>Δ Spacing Z5 [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tego II. IM55</td>
<td>990</td>
<td>2</td>
</tr>
<tr>
<td>Tego II. T16ES</td>
<td>990</td>
<td>2</td>
</tr>
<tr>
<td>IL 3</td>
<td>990</td>
<td>3</td>
</tr>
<tr>
<td>IL 4</td>
<td>990</td>
<td>4</td>
</tr>
<tr>
<td>4:1 mixture of IL 4 and Tego II. IM55</td>
<td>990</td>
<td>4</td>
</tr>
</tbody>
</table>

Hydredraw 768 is a high-performance lubricant for hydroforming which is marketed by the DA Stuart Company.

[0222] Tego II. IM55 = 1-ethyl-4,5-dihydro-3-(2-hydroxyethyl)-2-(8-heptadecenyl)-1H-imidazolium ethylsulphate CAS No. 68039-12-3

[0223] Tego II. T16ES = tetraalkylylammonium sulphate, 68071-95-4

IL 3 = dimethylidiallyl ammonium acetate

IL 4 = hydroxyethylmethylmorpholinium methylsulphonate

[0224] Tego II. IM55 = 1-ethyl-4,5-dihydro-3-(2-hydroxyethyl)-2-(8-heptadecenyl)-1H-imidazolium ethylsulphate CAS No. 68039-12-3

[0225] Tego II. T16ES = tetraalkylylammonium sulphate, 68071-95-4

[0226] IL 3 = dimethylidiallyl ammonium acetate

[0227] IL 4 = hydroxyethylmethylmorpholinium methylsulphonate

[0228] The results clearly show that the ionic liquids according to the invention are significantly better lubricants in hydroforming processes than the industrial solutions used hitherto. The experiments also show that mixing of various ionic liquids makes it possible to produce lubricants having adjustable viscosity values (Tego II. IM55 and IL4 give a
lubricant whose viscosity is between the low viscosity of Tego IL IM55 and the high viscosity of IL4) which can advantageously be used in the hydroforming process.

[0229] Having thus described in detail various embodiments of the present invention, it is to be understood that many apparent variations thereof are possible without departing from the spirit or scope of the present invention.

1. An ionic liquid which comprises of an ionic salt of the general formulæ I, I or I:

\[
[A]^n\ Y^m^-
\]

where \( n = 1, 2, 3 \) or \( 4 \), \( [A]^n \) is a quaternary ammonium cation, an oxonium cation, a sulphonium cation or a phosphonium cation and \( [Y]^m^+ \) is a monovalent, divalent, trivalent or tetravalent anion; or mixed salts of the general formulæ (II)

\[
[A]^n\ [A']^n\ [Y]^m^-
\]

where \( [A]^n, [A']^n \) and \( [Y]^m^+ \) are as defined for formula I or

\[
[A]^n\ [A']^n\ [A'']^n\ [A''']^n\ [Y]^m^-
\]

where \( [A'^n], [A''^n], [A'''^n] \) and \( [A'''']^n \) are as defined for formulæ (I) or mixed salts of the general formulæ (III)

\[
[A]^n\ [A']^n\ [M]^n\ [Y]^m^-
\]

\[
[A]^n\ [A']^n\ [M]^n\ [M]^n\ [Y]^m^-
\]

\[
[A]^n\ [A']^n\ [M]^n\ [Y]^m^-
\]

\[
[A]^n\ [A']^n\ [M]^n\ [Y]^m^-
\]

\[
[A]^n\ [A']^n\ [M]^n\ [Y]^m^-
\]

where \( [A'^n], [A''^n] \) and \( [A'''^n] \) are as defined for formulæ (I) or mixed salts of the general formulæ I-III.

2. The ionic liquid of claim 1, wherein the ionic salt comprises of at least one anion selected from the group consisting of halides, carboxylates, phosphates, thiocyanates, isothiocy-

anates, dicyanamides, sulphones, alkylsulphonates, sulphonates, alkylsulphonates, tetrafluoroborate, hexafluorophosphate and bis(trifluoromethyl)sulphonylimide combined with, substituted ammonium, phosphonium, pyridinium or imidazo-

lium cations.

3. The ionic liquid of claim 1 wherein the ionic salt comprises of at least one cation of the general formulæ:

\[
R^m\ R^m\ R^m\ R^m\ N^-
\]

\[
R^m\ N^m=CR^mR^m
\]

\[
R^m\ R^m\ R^m\ R^m^+\ +
\]

where

\( R^1, R^2, R^3, R^4 \) are identical or different and are each hydrogen, a linear or branched aliphatic hydro-carbon radical which has from 1 to 30 carbon atoms and may contain a double bond, a cycloaliphatic hydro-carbon radical which has from 5 to 40 carbon atoms and may contain a double bond, an aromatic hydro-carbon radical having from 6 to 40 carbon atoms, a phenylaryl radical having from 7 to 40 carbon atoms, a linear or branched aliphatic hydro-carbon radical which has from 2 to 30 carbon atoms and is interrupted by one or more hetero-atoms (oxygen, NH, NR where \( R^1 \) is a C-\( C_{30}-alkyl \) radical which may contain double bonds, in particular —CH=— and may contain double bonds, a linear or branched aliphatic hydro-carbon radical which has from 2 to 30 carbon atoms and is interrupted by one or more hetero-atoms selected from the group consisting of 

\( —O—C(O)—O—, —O—N—C(O)—, —O—C—N(C(O))—, —O—C—N(CH_3)—, —SO_2—O—, —O—SO_2—, —SO_2—N(CH_3)—, —N(CH_3)—SO_2—, —SO_2—N(CH_3)—, —N(CH_3)—SO_2—, and may contain double bonds, a linear or branched aliphatic or cycloaliphatic hydro-carbon radical which has from 1 to 30 carbon atoms and is functionalized terminally by OH, OR, NH_2, N(R)^2 (where \( R^2 \) is a C_1, C_30-alkyl radical which may contain double bonds) and may contain double bonds or a polyether which may have a block or random structure and has the formula \( —(R^2—O)_n—R^2= —(R^2—O)_n—R^2= —(R^2—O)_n—R^2= \).

4. A method of noncutting forming of metallic workpieces which comprises applying at least one ionic liquid or a mixture of ionic liquids as defined in claim 1 to a precursor metallic object.

5. The method of claim 4, wherein the noncutting forming is internal high-pressure forming.

6. The method of claim 5, wherein the ionic liquid or the mixture or ionic liquids is used as external lubrication and/or as pressure medium and/or as heat transfer fluid.

7. The method of claim 6, wherein the ionic liquid or the mixture or ionic liquids has a melting point below 100° C.

8. The method of claim 7, wherein the ionic liquid or the mixture of ionic liquids has a melting point below 50° C.
9. The method of claim 6, wherein the ionic liquid used as external lubrication in a noncutting forming process or the mixture of ionic liquids has a melting point above room temperature.

10. The method of claim 6, wherein the ionic liquid or the mixture of ionic liquids has a liquid range from -50°C. to 400°C.

11. The method of claim 6, wherein the ionic liquid or the mixture of ionic liquids has a liquid range from -40°C. to 380°C.

12. The method of claim 6, wherein the ionic liquid or the mixture of ionic liquids has a liquid range from -30°C. to 350°C.

13. The method of claim 6, wherein the ionic liquid or the mixture of ionic liquids has a decomposition temperature above 300°C.